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AN EXPERIMENTAL INVESTIGATION OF RECOVERY FROM WORK

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By
S. L. CRAWLEY, M. A.

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Submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in the Faculty of Philosophy,
Columbia University

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INTRODUCTION

Investigations upon the effects of work cover as wide a field as any separate factor in theoretical or applied human behavior. Extended discussions of subjective sensibilities, chemical formulae, and gross physical measurement of quantitative output under controlled conditions, vie with one another as means by which a practically interested experimenter or employer may say, "Given these conditions, with this type of responding organism, I shall expect certain corresponding phenomena." With the dismissal of attempts to discover and measure a certain state *per se*, the emphasis is being placed upon the observation of controlled situations, which produce results applicable to those or very similar conditions. Dissatisfaction as to the bare concept of "fatigue" has been registered,[1] along with censorship of too widespread application of artificial results as such to workshop conditions.[2]

The laboratory policy of varying only one condition at a time, the rest to be held constant, affects the results obtained through voluntary work by the human organism more than in any other definitely objective situation.[3] Variations in work curves obtained over extended intervals of time have shown fluctuations not at all in harmony with any increase or decrease of the metabolism of the subject involved. These changes are usually attributed to some vague mental state, the problem seemingly answered when the source of error is given a name. Experiments can be made, however, on the actual effects of the secondary influences, and as a result are of value

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[1] Watson, J. B., *Psychology from the Standpoint of a Behaviorist.* (2 ed.) p. 369.

[2] Polakov, W. N., *Carbon Dioxide as an Index of Fatigue.* Mechanical Engineering, Vol. 25, p. 1043.

"Laboratory experiments on the fatigue of single muscles, group of muscles and nerve centers by means of dynamometers, ergographs, etc., while shedding much light on the problem, did not take into account the fact that in shop work the character of the operations usually provides cyclic relaxation. Neither did it study the worker as a whole, and, studying elements, it had little to contribute to the solution of actual problems."

[3] Woodworth, R. S. and Poffenberger, A. T., *Experimental Psychology.* (Mim.) Chap. 1.

to later investigations which are connected directly or indirectly with these disturbances.[4] [5]

Our present problem developed from a desire to measure the effects of variation in tasks or conditions upon a succeeding standard form of behavior. If we can control a given performance, which in itself will have all the properties of a typical work curve, then any extreme exertion on the part of the subject at a time shortly preceding the standard task should, all things being equal, have some influencing mark upon it.

The data obtained were to a great extent dependent upon full co-operation of the participants. This factor was considered in the selection of the subjects. The results are believed to be as free from "soldiering" as is possible in the case of voluntary standards of exhaustion on the part of the subject.

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[4] Morgan, J. J. B., *Overcoming Distractions*, Archives of Psychology. 35.

[5] Johanson, A. M., *Influence of Incentive and Punishment on Reaction Time.* Archives of Psychology. 54.

CHAPTER I

The Effects of Work

A. *Conceptions of Fatigue:*

Fatigue is the general term usually employed to show that the working organism is influenced by continuing some activity to the point where the activity itself may cease; the activity may merely be reduced to a lower level of performance and then carried on indefinitely on this reduced plane; or the performance itself may remain at the initial level, but accessory mechanisms may be affected so that extraneous symptoms are present. This three-fold distinction among work curves is demonstrated in a different light by Spaeth[1] in showing how such types are obtained from mere differences in difficulty of the task (size of weights). Hough,[2] 1901, showed that similar results could be secured by keeping the task constant (i.e. the size of the weights to be lifted by the ergograph) and varying the interval between contractions. "The height of the fatigue level varies inversely with the rapidity of the rhythm of contraction."

Ash[3] uses the term fatigue to mean "all those immediate and temporary changes, whether of a functional or organic nature, which take place within an organism or any of its constituent parts as a direct result of its own exertions and which tend to interfere or inhibit the organism's further activity." Spaeth[4] considers fatigue as a "lowered capacity for work, resulting directly from the accumulation of the products of activity, and varying with the duration, rate, and intensity of the performance and the initial strength or capacity of the physical system involved." These sample definitions demonstrate the usual considerations of the condition of fatigue.

In the presidential address before the American Psychological Association, 1916, Dodge[5] introduced several important

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[1] Spaeth, R. A., *Problem of Fatigue*, Journal of Industrial Hygiene, May, 1919.

[2] Hough, T., *Ergographic Studies in Neuro-Muscular Fatigue*, American Journal of Physiology. Vol. 5.

[3] Ash, I. A., *Fatigue and Its Effects Upon Control*, Archives, 31.

[4] Spaeth, R. A., *op. cit.*

[5] Dodge, R., *The Laws of Relative Fatigue*, Psychological Review, XXIV, 1917.

considerations dealing with mental fatigue. Although this approach is outside the realm of our present investigation, nevertheless some of his conclusions bear directly upon the field of fatigue in general and are therefore of significance. Most mental fatigue, according to Dodge, is induced through factors other than neural fatigue. All of these affect the performance, and as a result the work decrement may not be through actual fatigue, but because of inhibitions, fluctuations in attention, boredom, etc. He applies the name "pseudo-fatigue" to the work decrement that results from such causes. Dodge furnishes us with two laws of relative fatigue: "Within physioligical limits, all fatigue decrement in the results of work is relative to the intensity of the stimulus." Furthermore, "fatigue is relative not only in the relation of apparent work decrement to stimulus, but it is also relative in the sense of a proportionate fatigue of the various factors in a competing group. In any complex of competing tendencies, the relatively greater fatigue of one will tend to eliminate it from the competition in favor of the less fatigued tendencies."

Muscio[6] has presented a more pertinent article wherein he questions the possibility of a fatigue test actually existing. Fatigue should be recognized in its characteristic expression, whether we know about it exhaustively or not. The general definition that fatigue is a condition caused by work, in which the capacity for work is diminished, is revised by Muscio so that ambiguities in the interpretations of the term "work" and the phrase "diminished capacity" (as an expression of fatigue) will be avoided. The revised definition would be: "Fatigue is a condition (partly specifiable by reference to accumulation of metabolites and blocking in impulse paths) caused by activity in which the output produced by that activity tends to be relatively poor; and the degree of fatigue tends to vary directly with the poorness of the output." The possibility of finding a fatigue test thus depends upon eliminating or determining the precise effects of all interfering factors (including factors tending to produce the accepted characteristic expression of fatigue in the absence of the fatigued condition). These determining factors are usually found in incitement, practise, spurts, illness, diurnal rhythm, incentives to a given kind of activity, and competing incentives.

[6]Muscio, B., *Is a Fatigue Test Possible?* British Journal of Psychology. Vol. XII, 1921.

Muscio concludes by advising that the term "fatigue" be banished from precise scientific discussion; and with it, attempts to procure a "fatigue test." Instead, "the problem should be defined as the determination of the effects of different kinds and amounts of work (activity) upon mental and physiological functions, i.e. that the kind and amount of work be correlated directly with changes in psycho-physiological functions, and not, as at present, indirectly by means of "fatigue." The various proposed fatigue tests would then be used to determine "effects of activity," and not the "presence or absence of fatigue."

From the above definitions we may isolate certain factors bearing directly upon the preliminary approach to any work problem. The first of these is that the heavier the weight, the more rapid the fall in the work curve. The second is that a long interval between contractions produces the same sort of effect (as far as continuation of the curve is concerned) as the employment of a light weight. A third important factor is the recognition of the subjective attitude upon the part of the performer of voluntary fatigue activity.

Concerning this last factor one is aware of a dual aspect that deserves attention. As far as output is concerned, the feeling of the subject as to his ability for any given time has been shown to have no high degree of relationship with his possible performance,—the subject often producing maximal work after stating that he believes himself at a very low ebb of capability.[7] [8] [9] [10] On the other hand, the attitude of a performer towards the task in general, especially where the task is extended over a long period of time, greatly modifies his actual performance. This is shown most specifically in tasks where the work limit is based upon the subject's own criterion of exhaustion.[11] Spaeth[12] considers this in his further explanation of fatigue:

"If, then, we are actually in a position to release layer after layer of energy under emotional stress, our problem of fatigue becomes tremendously more complex. Indeed, to say

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[7] Myers, C. S., *Mind and Work*, p. 41.
[8] Fox, C., *Educational Psychology*, Chap. XII, p. 327.
[9] Rivers, W. H. R., *Influence of Alcohol, etc., on Fatigue*, 1908.
[10] Smith, M., *Contributions to the Study of Fatigue*, British Journal of Psychology, Vol. VIII.
[11] Wright, Wm. R., *Some Effects of Incentive on Work and Fatigue.* Psychological Review. Vol. 13, 1906.
[12] Spaeth, R. A., *op. cit.*

that fatigue is a diminution of working capacity, a definition that constantly appears in the literature, may cover all those cases, such as many of the laboratory experiments, in which no emotion factor complicates the result. But, with the wide range of emotions that occur in different individuals under varying conditions of daily life, especially under the conditions of industrial life, fatigue comes to mean something quite different from a simple diminution of working capacity. We may qualify our original definition, then, by saying that under normal conditions, in the absence of emotive stimuli, fatigue is expressed by a lowering in the capacity for work of the normal individual."

How all of these factors were considered in the present investigation will be discussed as they appear in the development of the problem and methods.

B. *Locus of Fatigue:*

As far as the exact localization of fatigue in specific parts of the organism is concerned, no one theory holds the respect of all investigators.[13] In general the chemical theory of decrease in existing necessary substances and the increase in waste products seems to be widely acceptable. Where the effect actually is first noticed is varyingly claimed for the peripheral organs, the motor end-plates, the general synapses, and the nerve centers.

Mosso,[14] Lombard,[15] and Waller[16] demonstrated that when the muscle ceased to respond to voluntary stimuli, contractions still could be produced through electrical stimulations of the muscle directly. Mosso held this phenomenon to be due to the fact that the central nervous system was affected first, protecting the actual responding mechanism, the muscle, from dangerous depletion. The same data was interpreted as showing that it is the motor end-plate that was affected, since

[13] Burnham, W., *The Problem of Fatigue,* American Journal of Psychology, 1908, Vol. 19. p. 395. "question is still unsettled whether fatigue resulting from ordinary neuro-muscular work is primarily central or peripheral ..... does not seem as yet satisfactorily settled whether the nerve center or the peripheral is better able to resist fatigue although it seems probable that the nerve center has greater resistance."

[14] Mosso, *Fatigue,* N. Y., 1904.

[15] Lombard, W. P., *The Effect of Fatigue on Voluntary Muscular Contractions,* American Journal of Psychology, 1890, Vol. III, pp. 24-42.

[16] Waller, A., *Experiments and Observations Relating to the Process of Fatigue and Recovery.* British Medical Journal, 1885, Vol. II, pp. 135-148.

nerve fibres have been shown in themselves to be immune to fatigue. Abelaus,[17] Lombard,[15] Waller,[16] Santesson,[18] Ioteyko,[19] held to this view. Schenk[20] criticised the work of Santesson, and found that from his own data, the nerves and the nerve endings were still active and that is was the area in the muscle immediately surrounding the end-plate, where fatigue was located. Kraepelin,[21] Hough,[22] Woodworth,[23] Storey,[24] Ioteyko,[19] all show that these muscles which were stimulated first to voluntary exhaustion, and those that were stimulated electrically were not the same muscles. The peripheral theory probably holds greater respect at the present time than any other. The chemical changes in the muscle itself are too obvious to be ignored.

As this has only theoretical interest for our problem no elaboration upon this phase will be presented.

C. *Experimental Studies.*

Fatigue as an object of experiment falls quite naturally into two large classes of subject matter. The first uses as its medium the intact living organism, which is controlled and made to perform a further carefully controlled task. The effects of the performed task upon further capacity of the subject, or upon changes within the organism are then measured. A second class—and one of greater historical significance—are those physiological experiments where the observed cells or muscle tissues affected are isolated or removed from the functioning organism. Many modifications of the two classes develop. All work under "natural"[25] or voluntary

[17] Abelaus, J. E., *De la Fatigue,* Archives de Physiol., 1893, pp. 720-728.

[18] Santesson, C. G., *Einige Bemerkungen uber die Ermudigkeit der motorischen Nervenendungen und der Muskelsubstanz,* Skand. Arch. fur Physiol., 1895, Vol. V, pp. 394-406.

[19] Ioteyko, J., *La Fatigue,* Richet's Dictionnaire de Physiol., 1903, Vol. VI, pp. 29-213.

[20] Schenk, F., *Untersuchungen uber die Natur einiger Daurcontractionen des Muskels,* Arch. g. P., 1895, V, 61, pp. 494-555.

[21] Kraepelin, E., *Uber die Beiinflussung einfacher psychischer Vorgange durch einige Arsneimittel,* Experimentelle Untersuchungen, Jena, 1892.

[22] Hough, T., *Ergographic Studies in Neuro-muscular Fatigue,* American Journal of Physiology, 1901, V.

[23] Woodworth, R. S., *On the Fatigue of the Nerve Centers,* New York University Bulletin of Medical Science, 1901, I, pp. 133-139.

[24] Storey, Thomas, *Variations in the Amplitude of the Contractions of Human Voluntary Muscle in Response to Graded Variations in the Strength of Induced Shock,* American Journal of Physiology, 1903, VIII, pp. 435-440.

[25] Mosso, A., *op. cit.*

fatigue falls easily under the first heading, but the many discoveries of the type and properties of the fatigue substances themselves have resulted from experiments in both fields.

Reviews of the general work in fatigue are found in articles by Burnham,[26] Yoakum,[27] Lee,[28] and Spaeth.[29] The last named work contains a comprehensive bibliography for all possible applications of the problem.

In Poffenberger's Applied Psychology,[30] we find a convenient classification of the various types of experimentation upon work effects. These may be used here in tracing the historical development of the various modifications of this field.

The first group falls under the category of measuring fatigue directly in terms of output,—where the data are obtained by noting the variations in a curve of performance under controlled conditions. The only standard or norm required is the knowledge of the performance of the subject under conditions wherein he is not fatigued; from this, decreases in performance are looked upon as fatigue symptoms. As an original source, Kronecker's[31] contribution on the work curve of an isolated extirpated muscle probably deserves greatest recognition. His laws of fatigue-curve characteristics under such conditions are still classic, stating that the fatigue of a muscle which contracts at regular intervals may be represented by a straight line; furthermore, the height of the contraction diminishes the more rapid the rhythm in which they are produced, and vice versa. Mosso,[32] the name usually associated with the pioneer work in voluntary fatigue, was himself greatly influenced by the methods and technique of Kronecker. The ergograph was developed by Mosso, allowing more accurate measurement of performance of work by the intact organism. Treves[33] [34] later showed that the exhaustion

[26] Burnham, W., *Problem of Fatigue*, American Journal of Psychology, pp. 4-19.

[27] Yoakum, C. S., *Experimental Study of Fatigue*, Chicago, 1909, Ph. D. dissertation.

[28] Lee, F. S., *Fatigue*, Harvey Lectures, 1906.

[29] Spaeth, *op. cit.*

[30] Poffenberger, A. T., *Applied Psychology*, Appleton & Co. (in press).

[31] Kronecker, H., *Ueber die Urmudung und Erholung in quergestreiften muskeln*, Ber. u.d. Vehr. d.k. bachs. gesel d. Wiss., Math.-phys., 1871, v. 31.

[32] Mosso, A., *Fatigue*, 1915, Putnams, p. 81.

[33] Treves, Z., *Ueber den gegenwartigen Stand unserer Kenntnissbetreffend die Ergographie*, Pfluger's Archiv. Vol. 88, 1902.

[34] Treves, Z., *Le Travail, La Fatigue, et L'Effort*, L'Annee Psychologique. Vol. 12, 1906, Paris, pp. 34-69.

limit obtained by the weight ergograph was only relative, and dependent directly upon the task at hand. If successive amounts of weight were removed as the work curve approached a low level of performance, the curve would immediately rise. This allowed for a closer approximation of absolute exhaustion. The rapid increase in the number of modifications of the ergograph allowed further development in this field of voluntary muscle exhaustion. The spring ergograph and dynamometer were devised, allowing constant reduction in task as fatigue set in. Many experiments as to the importance of procedure in employing ergographic tasks also developed.[35] [36] Further emphasis was placed on the relativity and dependence of task to the time of contraction, the completeness of relaxation between strokes, and the size of the weights used.[37] [38] [39] [40]

Under this same heading, investigating the performance curve itself, a great deal of material has been gathered on the characteristics of the mental fatigue curve. As this has no bearing upon our task at hand, mere recognition of this field will suffice, especially since no definitely obvious data have been consistenly proven, other than a seeming high resistance to the fatigue brought about by continuous activity.

The second large category has to do with the expression of fatigue in terms of the effects upon accessory mechanisms. Under this heading we may mention Ryan's[44] Vascular Skin Reaction Test; Kent's[42] work on effects of fatigue upon visual and auditory acuity; Martin and Rich's[43] Strength Test; Martin, Withington, and Putnams'[44] results as to the Threshold of

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[35] Weiler, Karl, *Untersuchung uber die Muskelarbeit des Menschen*, Psychologische Arbeiten, Vol. 5, pp. 528-582.

[36] Cattell, J. McK., *An Ergometer*, Science, n.s. 5, 1909.

[37] Hough, T., 1901, *op. cit.*

[38] Woodworth, R. S., *Le Mouvement*, pp. 383-385.

[39] Treves, Z., *op. cit.*

[40] Arps, G. F., *Work with Knowledge, versus Work Without Knowledge of Results*, Psychological Monographs, 1920.

[41] Ryan, A. H., *Quantitative Measurement of General Fatigue*, American Journal of Physiology, Vol. 45, p. 537.

[42] Kent, A. F. S., *First Interim Report on an Investigation of Industrial Fatigue by Physiological Methods*, Darling & Son, London, 1915.
Second Interim Report on an Investigation of Industrial Fatigue by Physiological Methods, Darling & Son, London, 1916.

[43] Martin, E. G., *Strength Tests in Industry*, American Journal of Physiology, V. 45, p. 45.

[44] Martin, E. G., Withington, P. R. and Putnams, J. J., *Variations in the Sensory Threshold for Faradic Stimulation in Normal Human Subjects*, American Journal of Physiology, Vol. 34.

Faradic Stimulation; Abalson's[45] Aethesiometer Test; Ash's[46] contribution as to the variations through fatigue in voluntary attempts upon the part of the subjects in changing perspectives; and McDougall's[47] work on Attention. All of these have shown, or attempted to show, that a fatigued state will manifest itself in mechanisms accessory to those involved in the fatiguing work.

A third category includes those experiments which express fatigue in terms of work done by mechanisms extraneous to those involved in the process. Records are taken showing how other parts of the organism, probably relief mechanisms, are thrown into activity while performance takes place. McDougall discussed this in the Report of the British Association for the Advancement of Science, 1908 (Dublin). In most experiments this factor is ruled out by controls as a variable influencing results. Morgan's[48] work on distraction is of interest in showing that increased force and additional actions are called into play under stress. Ash also measured various muscular changes in control through fatigue. Probably glandular activities, although just as correctly falling under the metabolic category, would belong here under certain experimental procedures.

Where fatigue is observed in terms of changes in metabolism, the fourth large grouping, we have a vast amount of material taken over from the physiologists directly. Here again different aims cause a distinction to be made between those investigations which were made primarily to show the effects upon certain organic balances, isolating and studying these as such, and those investigations which were made in order to take this metabolic change as an index for the fatigue state. Various reports from the Industrial Fatigue Research Board use this method in determining fatigue effects. In Report 29, an article by E. M. Bedale[49] shows the optimum type of carrying loads in terms of metabolic changes. In the same re-

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[45] Abalson, A. R., *Mental Fatigue and its Measurement by the Aethesiometer*, Internat. Archiv. of Schulhyg. V. band.

[46] Ash, I. E., *op. cit.*

[47] McDougall, Wm., *New Method for Study of Concurrent Operations and of Mental Fatigue*, British Journal of Psychology, Vol. 4, 1905, p. 435.

[48] Morgan, J. J. B., *Influence of Distractions, etc.*, 1916, Archives of Psychology, 35.

[49] Bedale, E. M., *Comparison of Energy Expenditure in Carrying Loads.*

port Vernon[50] finds a noticeable effect produced in a work curve when posture is changed during the rest period, as compared with situations where the posture is kept absolutely the same. Doubtless a heightened removal of the fatigue toxins through activity allows for this difference.

Without elaborating upon this field of experimentation, especially in its more or less applied forms, mention should be made of the researches which actually show the chemical composition of the fatigued state of the tissue. In a recently published series of lectures, Hill[51] gives a most authoritative account of this side of the question, including with it an excellent bibliography of the field. In brief, since the classical work of Fletcher and Hopkins in 1907, and the later works of Meyerhof and others, there have been discovered the following chemical changes in muscular activity: the disappearance of glycogen; the appearance of lactic acid in equivalent amount; preformed CO_2 is driven off; heat, in proportion to the amount of lactic acid formed, is produced; and the hydrogen ion concentration rises. From these major assumptions many other interesting phenomena have been observed, especially due to the transference of these local fatigue toxins to other parts of the body. The efficacy of rest periods depends a great deal upon this factor, for the most rapid recovery of local muscular activity due to the recuperative supplying of oxygen, etc., in the blood, is not the only qualification. This same circulatory system has previously distributed the fatigue toxins throughout the body, requiring longer periods of rest to remove entirely the toxic effects. The two hour interval set by Mosso and others accounts for this entire recuperation, while the variability in amounts of work separted by short rests (around fifteen minutes) whereby a second work period might be as large or greater than the first—as found by Manzer and others in unpublished reports of experiments conducted in the Psychological Laboratory of Columbia University—is no doubt due to the fact that the task is so short and sufficiently localized that the time of rest used was long enough to allow for this local flushing of the muscle, with the result that recovery was practically complete. The effects of just such experiments are considered in the method employed in the present investigation.

[50] Vernon, H. M., *op. cit.*
[51] Hill, A. V., *Muscular Activity*, Herter Lectures, 1926.

Lee[52] has shown that if these same fatigue substances are supplied in a small amount over a long interval, or in a greater amount in a small interval of work, they may, instead of toxic, be actually stimulating. The characteristic "treppe" feature at the beginning of the muscle-work curve is explained by him in this manner. However, when these substances accumulate in larger quantities, they assume their toxic feature and the curve falls away, approaching exhaustion or the fatigue level. This last is a balance line where seemingly the removal of the fatigue substances is as rapid as their accumulation.

The works of Carpenter and Benedict[53] with their calorimetry tests, that of Hastings showing effect of fatigue as shown in properties in the blood supply and in urine,[54] Cannon's adrenalin secretion factor,[55] etc., tend towards a metabolic conception of fatigue.

And in so far as these metabolic tests may be taken from the subjects without influencing their normal output at the required task by artificial inconveniences, there is no doubt but that this method of measuring the condition of the subject at certain times to exhaustion or to the optimum level of productivity will be the most important method of applied technique. Its greatest advantage lies in its freedom from those emotional sources of error pointed out above in the voluntary work curve, and also in the case of objective measurement.

Our final category probably offers the most efficient means of standardization of the voluntary work curve. This type is in terms of time required for recovery, or more important still, the amount of recovery in a fixed time. The main point of departure from the first general type is that although the work period is measured and considered, a break or a modification is introduced—usually a rest after exhaustion—and the effect is noted on a second performance. Both the first and the second periods may be varied, as well as the length of interspersed rest.

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[52] Lee, F. S., *Cause of the Treppe*, American Journal of Physiology, Vol. 18, Vol. 20.

[53] Benedict, F. G. and Carpenter, T. M. *Influence of Muscular and Mental Work on Metabolism*, Bulletin U. S. Dept. Agriculture, No. 208.

[54] Hastings, A. B., *Physiology of Fatigue*, 1920, (1) Col. Univ., Ph. D. *Dissertation;* (2) U. S. Dept. of Labor Statistics, Bulletin No. 221.

[55] Cannon, W., *Bodily Changes in Fear, Rage, Pain, and Hunger.*

Under this heading there is a work by Wright[56] which appeared in the Psychological Review, 1906, which has direct bearing upon the conditions of our experiment. The apparatus used by him was the Catell spring ergograph. "The metronome was set to strike twice a second. The subject worked with his left hand. The fingers of the hand were placed under the base of the ergograph, and the carriage of the instrument was moved downward by the thumb once each second." With the one task all incentive, as the watching of the instrument or keeping track of his progress by counting strokes, was denied the subject; whereas under a second condition the subject was not only permitted to watch his strokes, but was also stimulated to action part of the time by being requested to count his strokes..... The subject worked with his left hand, moving the carriage down with the thumb. As a motive for the second class—the incentive—blocks of varying thicknesses were put under the platform at such a distance that the subject could with fair exertion reach them. The subject was required merely to push to the block and to exert himself to see how many times he could reach it. After failing to reach the block he still pressed as closely to it as he could until his strength failed. Wright found that in practically every case the added influence of the incentive group caused increase in the quantity of work produced. One of the students of the Michigan laboratory in 1903 made use of the ergograph in testing fatigue. His series were of the two types described above, although the point of incentive was only inadvertently hit upon. By partially fatiguing a group of muscles in one series with the length of the stroke stopped at a specific point by means of the block, and in the other by allowing the full stroke, then allowing the curve to continue from this same quantitatively similar point of departure, it was assumed that the amount of work required to induce complete fatigue from that point would be indicative of the effects of the previously performed work. Results showed that not only was more work done in the first forty or sixty contractions where the subject worked down to the block (definitely an incentive), but also in spite of this increased quantity, the amount of work done from that point on (no rest was interspersed) was greater than that done when no block (i.e. no

[56] Wright, W. R., *Some Effects of Incentive on Work and Fatigue*, Psychological Review, 1906.

incentive) was present. Wright draws the following conclusions:

1. The subject accomplished more work when working under the mental stimulus of having a set task to be performed than he did when working without a special aim.

2. A known impossibility to accomplish the required conditions tends to decrease the subject's total results.

3. The fatigue accompanying work is not so great when the subject is working under the direct stimulus of a definite aim, notwithstanding the fact that he has at the same time produced an increase in his amount of work.

As the above conclusions bear directly upon our present problem, we shall examine them in closer detail. In the first place, as to increased amount of work produced with known results, etc., or incentive, this fact may be safely accepted as true. Arps[57] has more recently found the same phenomenon, and Johanson[58] has demonstrated it in reaction time. Futhermore, it is being constantly applied to all occupations where competition, either self or in groups, is used as incentive. In the present work the same principle was incorporated as one of the variables, with results in absolute accord with the previous experiments. That is, even where the subject is compelled to work to exhaustion, and where he makes positive statements that he has gone his complete limit, if he competes with this record at a later date, the chances are practically certain that under this condition of motivation and visible results, a greater amount of work will be produced.

Wright has also demonstrated that when the goal is too far removed, the tendency is not to go as far as possible, but to be more or less discouraged and do even less than he might do under more ordinary conditions. The application of this conclusion to our problem will be taken up at a later stage, although no negative effects of extreme competition were found as a universal fact in the present problem.

The third conclusion that incentive will produce more work with less fatigue, seems out of harmony with the law of conservation of energy, to say nothing of ordinary mechanics. In studying the procedure of the above investigation several fallacies can be observed. In the first case, although similar

[57] Arps, G. F., *Work with Knowledge of Results versus Work Without Knowledge of Results*, Psychological Monographs, 1920.

[58] Johanson, A. M., *op. cit.*

number of strokes were employed in the two series, and "approximately the same amount of work that could be recorded was performed under each condition (p. 26)," nevertheless the fact that the full stroke was not completed obviously shows that that part of the stroke which induces the most severe strain on the part of the subject, namely, the last few millimeters at the peak, was removed in the block control experiment; that even if in amount the records seemed approximate, the actual strain in the two situations was not at all identical. Furthermore, in the experiment as a whole, the subject continued this arbitrary point of measurement to the point of exhaustion without any interval separating the control part from the final measurable variable. From this it seems most fair to assume that the "control" parts of the two series were not identically controlled at all, and therefore their respective effects were not comparable. Surely a "mental set" can not be so readily dropped at a required point in a continuous work curve. What actually has happened is that the effect of incentive of the block, which is granted, carried over into the remaining strokes so that the subject merely produced the entire second curve under one "mental set" that was absent from the first. This bears directly upon our problem and it will be shown later, under Procedure, how this difficulty of carry-over of incentive was eliminated, at least to such an extent that the results are not contradictory to the laws of mechanics.

CHAPTER II

The Experiment

A. *Equipment:*

In the previous chapter emphasis was placed upon certain conditions that would directly influence the technique of the present experiment. These are of two classes: "attitudes" or "sets" governed by the subjects themselves; and those that are mechanically controlled through the setting and plan of procedure.

Our problem hinges upon the assumption that the effects of a task will have sufficient duration so that this will influence activity carried out in the interval normally spent in recuperation. By exercising an organism, then allowing a short interval of rest, and afterwards having a second standard task performed, effects of variation in the first should show in the second, granted that the rest interval was not too long to smooth out any local fatigue irregularities. Keeping these three elements in mind,—first task, rest, and second (standard) task,—any desired changes could be made at the will of the experimenter.

The subjects used were four men, two of them graduate students in the department of psychology, and the other two, graduate students in the department of English; all, however, were intimate acquaintances of the experimenter. This is merely mentioned to bear out the statement in the introductory remarks that high degree of co-operation could be assumed. In order to assure fairly regular participation, arrangements were made on an employment basis.

A set of printed directions was prepared beforehand. The experimenter read and demonstrated these to each subject before any records were made on the apparatus. In reading the directions the experimenter emphasized the fact that each work period was to be carried to actual exhaustion, and not merely to the point where the subject was "getting tired" of the task. This was referred to indirectly at various times throughout the course of the experiment, but without in any way reflecting or commenting upon the comparative value of

scores. Too great variations among the four subjects were early found so that group competition was not practical.

Only one subject at a time was allowed in the room when the experiment was in process. Each record was assumed as the subject's unqualified maximum output at that time for the task at hand. The temperature of the room was kept slightly lower than average class-room temperature, and ventilation was aided by keeping the window partly open at all work periods. In most cases the work period was of such short duration that only slight effects could have resulted from this cause.

The apparatus for both the arm and the leg experiments (See Figure I) was a modified form of the simple chest-weight apparatus found in pratically any gymnasium. The weights on such a mechanism are to be lifted vertically on guiding rods through force expended by the subject who grasps a handle connected by means of a rope and a double pulley attachment to the weights. The weights themselves are adjustable in size.

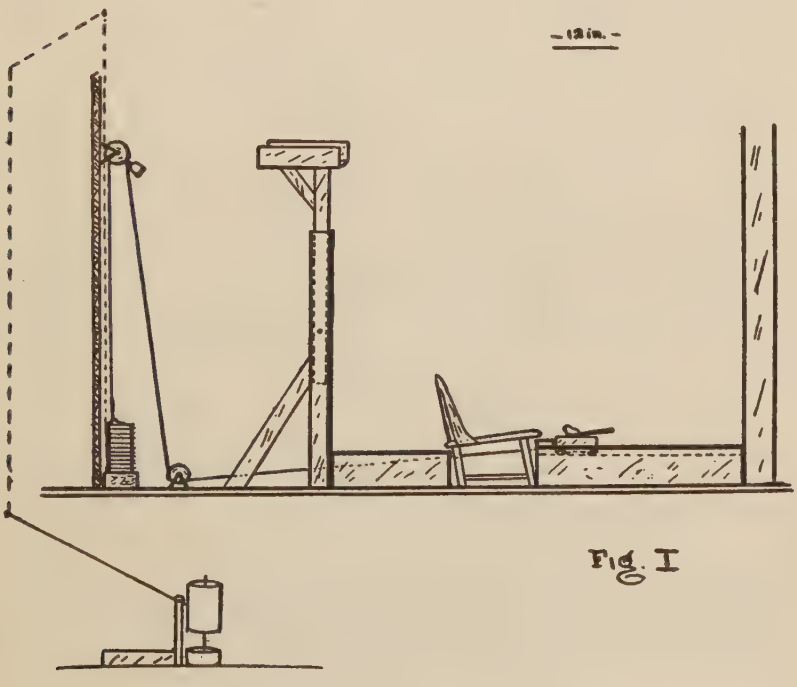


Fig. I

For our use one set of guiding rods was fastened on the wall of the laboratory, and the number of weights doubled. This, with additional weights constructed for the purpose, allowed a range of load varying from ten pounds to forty pounds. The extensity of the load was measured by spring scales at various times throughout the experiment to account for any changes brought about by increase or decrease of friction. The amount of the weight as stated is the actual load as lifted by the subject, not just the amount placed at the end of the pulley-rope attachment. In order to provide as large a weight as forty pounds, the double pulley was removed and a single one substituted.

Attached to the body of the weights was a rigid arm, and connected with this, and through a series of overhead pulleys a silk and cotton cord was connected with the recording lever which registered any change in position of the weights upon a smoked drum. The recording lever itself was counter-balanced at the extreme end by a slight weight which kept the string taut at all times, and which facilitated the downward movement of the lever. The fulcrum of the lever was approximately five centimeters from the recording tip (celluloid). This reduced the extent of the sweep so that only a very small curve was produced on the drum.

At a distance of about thirty inches from the weights, an upright stand was erected from the floor. The subject rested the upper part of his arm in a padded trough arranged so that it could be adjusted to suit the height of each subject. With the elbow as the point of leverage, all of the under part of the right arm rested in this trough; and as the trough was deep enough to allow no waste side movement, the general arc of the arm movement was kept constant throughout. The subject stood upon a platform raised eight inches from the floor.

The apparatus for the leg experiments was more complex than that for the arm. Continuing from the platform upon which the subject stood in performing work with the right arm was a chair elevated at about nine inches from the floor level. Continuing on from the chair there extended a guarded track upon which a rubber-tired, ball-bearing carriage could be moved. This carriage and runway were on the same plane as that of the chair seat. When the subject was seated in

this chair the arm apparatus and the moving weights were behind him, although it was possible to see the kymograph stand and metronome stand at his right. A cable connected the sliding carriage with the weights. This rope ran under the chair seat and under the platform of the arm experiment, through a stationary pulley fastened to the floor between the arm upright and the weights, then upwards, where it could be quickly hooked to the same point where the handle was connected for the arm experiments. This arrangement allowed for complete isolation of the two pieces of apparatus when either one was in use, yet at the same time both used the same adjustable weights.

When hooked up with the weights in the leg experiment, the carriage would be held securely against a bumper at that end of the track nearest the chair upon which the subject sat. The subject's foot and ankle were strapped to the carriage, so that the subject would be required to push outward with the right foot in order to move the weight. In the starting position the right leg of the subject would be bent upwards rather closely to his body, and a full stroke would call for complete extension of the leg. By having the subject seated on the same plane as that of the carriage, and by having him exert energy by pushing rather than by pulling, a compensatory strain was introduced so that the subject was forced to keep approximately the same position in the chair throughout the series.

In both the arm and the leg experiments, the subject was thoroughly impressed with the necessity of keeping in time with the metronome beats. In the case of the arm this called for a flexion every two seconds, the metronome being set at sixty. In the leg experiments it was found that this rate of activity was so slow that for some of the lighter weights a too prolonged fatigue curve would be produced for any practical purposes. For the leg series, the metronome was set at seventy-two, calling for thirty-six extensions of the right leg, under load, per minute.

The arm and the leg of each subject were under admitted strain during both the flexion and the extension. In the leg experiment, however, the bumper allowed for a slight relaxation as did complete extension of the arm, but the time of movement was so rapid in each case, this was minimized.

Outside the recognition of this factor, it has no special practical bearing on our task, as we were interested not in eliminating fatigue, but in inciting it under these controlled conditions.

The subjects were informed that the efforts to move the weights were recorded on the kymograph roll, and that even slight budges would be recorded. This was of course obvious when the subjects were allowed to observe their own records.

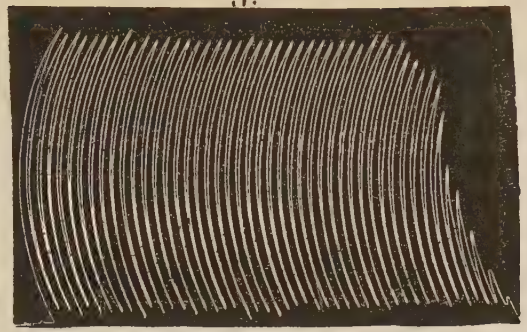
An interesting phenomenon appeared distinguishing definitely the two tasks performed from one another. The arm experiment, with the subject grasping the handle, flexing his arm, bringing it (the handle) up to his shoulder at definite intervals, as many times as possible, produced a typical voluntary fatigue curve, with full strokes at first and then a gradual diminution to the point of inability to lift the weight at all. For the leg experiment, however, it was discovered that the curve did not decline. The subject went so many strokes of full length, then was unable to make the next stroke (See Fig. II). When we observe the task as set by the leg experiment this has a very natural explanation. By requiring the subject to push out the carriage, we are causing him to exert his most severe energy at the start of the stroke. This arises from the fact that the knee as a fulcrum point is off center at start, and as the leg is extended obtains not only central point but also aids itself by pushing against the frame as the stroke is made. Actually the resting point in the case of the leg exertion is at the middle of the stroke rather than at the start or completion. The typical end of the work curve with the leg shows a futile attempt on the part of the subject to get the weight past "dead center." Although rather unusual, this is just as real an exhaustion point for this task as is the gradual decline in the arm experiment. If instead of allowing the subject to push against the weight, we had required him to pull the weight with his foot, a gradual decrease would have been in evidence.

B. *Procedure:*

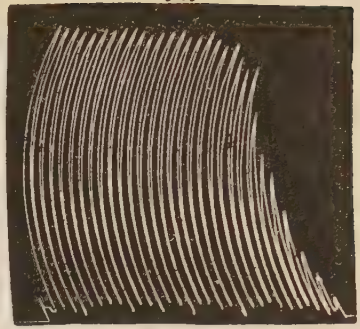
Two experiments upon each subject were performed each day, approximately five times a week. An arm record was taken in the morning at a special time for each subject; while in the latter part of the afternoon, usually between four and

— Fig. II —

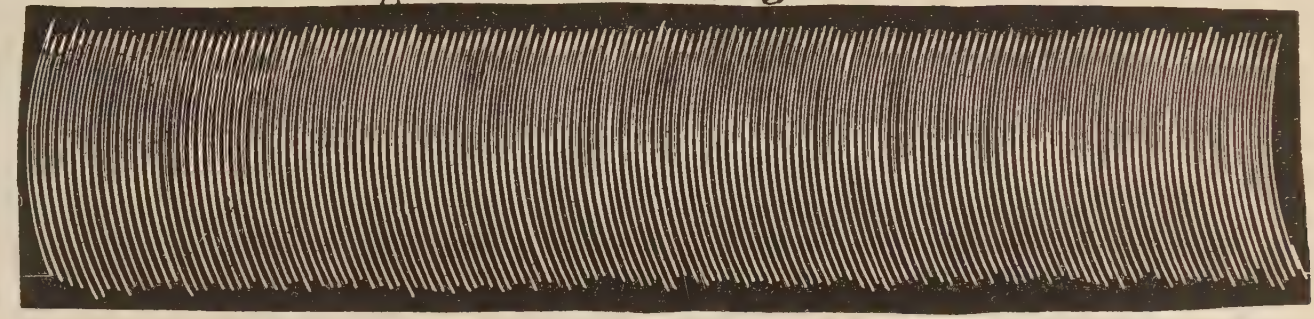
Typical Work Curves (Arm - 15lb. - 4 min. rest - 15 lb.)



(2)



Typical Work Curve (Leg)



six, a leg record was correspondingly taken. Any transference from arm activity to leg performance, or vice versa, was controlled by having both tasks each day. No possible continuance of fatigue from the arm exercise could affect the work done by the leg in the late afternoon, for not only were they two rather dissociated organs of the body, but in every case at least five hours separated the two periods. Only one subject at a time was allowed in the laboratory.

Each experimental session consisted of two work periods interspersed by a controlled rest period. The second work period in every case throughout the entire set of experiments was kept constant. This means that for the series of arm records the second work task was always performed by the subject upon a fifteen pound weight to the point of exhaustion. This allowed, as has been said, observations to be made upon this standard second task as to the effects of any variations in the first, other things being equal. Variations in the first task and in the length of the rest period were possible.

The following conditions were measured:

a. General arm performance as compared with leg performance.
b. In the arm experiments, the effects of ten, fifteen and twenty pound weights lifted in the first work period.
c. In the leg experiments, the effects of thirty, thirty-five and forty pound weights lifted in the first work period.
d. The effect of the two minute rest period as compared with a four minute rest period interspersed between the two tasks.
e. The effects of incentive in the first task upon the amount of work produced in the second.

The works by Wright,[1] James,[2] McDougall,[3] Judd,[4] Johanson,[5] and others, have proven to us that even where the subject swears that he has reached his maximum amount of output,—in our case designated by the point of exhaustion,—if the conditions are slightly altered, either through added

[1] Wright, W. R., *op. cit.*
[2] James, Wm., *Energies of Men.*
[3] McDougall, Wm., *Fatigue*, Rep. Brit. Assoc., 1908, Dublin.
[4] Judd, C. H., *Practise Without Knowledge of Results*, Psychological Review Monographs, Sup. II, 1905.
[5] Johanson, A. M., *Influence of Incentive and Punishment upon Reaction Time*, 1922, Archives of Psychology, 54.

praise, blame, knowledge of actual performance which is to be compared with some standard, competition with others or with his record, in other words some specific incentive or punishment, the subject will prove himself capable of producing more work than he himself has claimed as his utmost limit.

If we look at this situation as it actually appears, and do not attempt to cloak it with too great mysticism, there probably is nothing out of the ordinary about these differences in results between the two types of performance,—one with incentive and one without. The two situations are not identical, and naturally the types of response will be different. In one case the subject responds with those mechanisms or patterns of response that are satisfactory for that situation. In the other, he calls into play those that are satisfactory for this different situation. The difference may be due to heightened emotional tension, causing increased glandular activity, hence temporary immunization to fatigue effects; or it may be due to the ignoring on the part of the subject of those symptoms he has usually attended to as danger or exhaustion signs, whether truly or not. It may even be due to the calling into play of accessory mechanisms, or diffuse spreading of activity as pointed out by McDougall,[6] extra tension, etc.

The thing that has been present in the writings of industrial psychologists is the naive assumption that this increase in productivity may be accomplished with no extra penalty on the part of the organism. Such a conclusion as that found in the article of Wright discussed above seems out of harmony with any possible conception of the metabolism of the human organism. In industry this defect in ordinary cause and effect relationship may be glossed over by the introduction of frequent rest periods, and the realization that in only very rare occurrences will the individual go to that point where serious organic damage will result. The positive effects in industry obtained through the role of introduced incentives was not due to any ethereal qualities on the part of the incentive employed, but due to the fact that the worker had previously been performing at such a low state of possible performance that any increased change would bring about practically no katabolic process that could not be compensated for almost immediately (See Kitson).[7] However, if we have a task up

[6] McDougall, Wm., *op. cit.*
[7] Kitson, H. D., *The Psychology of Vocational Adjustment,* 1925.

for measurement that approaches the maximum performance of an individual and if we cause the individual to go beyond that point through his calling forth extra strain and exertion, it seems natural to expect that the extra effort will leave some effects upon the organic mechanism. These may be shown either in more disturbed metabolic processes not easily observable, or in the obvious diminishing of his immediate capacity to continue work.

With this problem in mind, variation in the experiment was introduced so that the output of a subject under this "no-incentive versus incentive" relation could be measured. It must be remembered that any variation was introduced only in the first work period. The second period, the screen upon which the variation effects were thrown, was kept constant.

Two general series of experiments were taken using this combination of factors for both the arm and the leg. The first series involved pairs of performances (with the recording apparatus screened from the subject),—interspersed by either a two or a four minute work period,—carried to the point of exhaustion. To distinguish this from the situation of absolute muscular exhaustion as is found by repeated direct electrical stimulation of the muscle, let us refer to it as voluntary exhaustion for the task at hand. This will give deference both to the phsiological limit of a muscle (not obtained by such an experiment as this), and also to the effects of reduction of weights even in a voluntary exhaustion experiment.[8]

In this first series, no incentive was applied to the first work period, other than the standard direction, to go to exhaustion.

In a second series, also interspersed by a two- or four-minute rest period, when the exhaustion point of the first period was reached, a modification was made in the performance of the first task for both arm and leg experiments. A horizontal line was marked out on the drum, or the terminus point shown, designating the extreme limit of the first work period of the subject's previous performance in lifting this weight without incentive. Furthermore, the screen, which had shielded the view of the recording drum from the sub-

[8] Treves, Z., *Le Travail, La Fatigue, et L'Effort*, L'Annee Psychologique, 1906.

ject during the non-incentive group, was removed, and the subject could not only see the goal (in horizontal plane) but also each successive stroke. This acted as a definite incentive situation throughout the experiment in both the arm and the leg tasks. The subjects responded to this self-competition most positively. After the new exhaustion point of the incentive series in the first task was reached, the screen was replaced during the rest period, and when the subject returned to his second task of the pair of performances (always the controlled one) no visible record of his activity was before him.

One theoretical preliminary difficulty as to whether there would be any carry-over of the incentive impetus to the second work period seems to have failed to put in an appearance. This probably was accounted for by the obvious break that was introduced by the rest, and the changed condition (replacing of the screen) under which the subject worked in the second period. As the problem progressed, this difference automatically became a natural state of affairs expected by the subject.

The above two series, with their respectively different rest periods, involved thirty-six pairs of performance, eighteen with incentive, and eighteen without. In each series of eighteen paired performances, there was introduced the three variations in weights in the first work periods,—ten, fifteen, and twenty pounds for the arm, and thirty, thirty-five, and forty for the leg. Each combination of factors (respective first period weight, with or without incentive, and two- or four-minute rest period, followed by standard second work task),—each combination was repeated twice. However, every unit in the combination task was found operative in more than just three periods. For example, in the arm experiments the influence of the two-minute rest period as compared with the four-minute rest could be traced in operation after the ten-, the fifteen-, and the twenty-pound weights, with and without incentive applied to the first work period. The same is true with the factor of incentive. This was traced through the influences of the various weights employed. Furthermore, it must be remembered that every combination used in the experiments on the right arm was duplicated (with the exception of the weight series being increased) in the leg experiments.

One other control factor must be mentioned here. Vernon[9] demonstrated the influence of change in position during the rest period, showing that where the subject was compelled to hold during the rest the same position that he assumed in the performance of the task, the effects of fatigue remained much more persistently (as shown in low after-rest performance) than if the subject changed his position however slightly during the rest interval. As our rest period of four minutes would have introduced difficulties in attempting to keep the subject in any one position for that length of time, and since this experimental task involved varying bodily positions from which it would have been difficult to choose one as typical of the performance, the subjects were allowed to move about the laboratory during the rest periods. Any distinct massaging, however, was not countenanced, for this would have had to have been consistently repeated throughout the series in order to keep such a recovery process controlled. Outside of recognition of these conditions, however, no further qualifications are necessary in explaining the amount of recovery as shown in the second work period.

To avoid any concentrated effects of practise, two controlling methods were employed. The first, and most natural, was the preliminary introduction of two practise series. The first of these was a group of ten pairs of performances, involving all possible combinations that would be used later in the experiment. This served the purpose of not only removing the effects of the initial practise rise, but at the same time allowed the experimenter to see if any of the intended combinations of factors were for some reason or other undesirable. A most immediate result was found in the case of a twenty-five pound weight in the leg experiment. Even at this early unpractised stage of the subject's condition, this weight was immediately seen to be too light a task. The change in metronome beats, for the leg experiment as distinguished from the one employed for the arm, was also early introduced. In the first practise group a part of the records were made with the second work period involving the same weight as the first, i.e., not the standard condition. This was done to see if the two- or the four-minute rest was sufficiently

[9] Vernon, H. M., *The Influence of Rest Pauses and Changes of Posture on the Capacity for Muscular Work*, Industrial Fatigue Research Board Report, 29.

small to disallow for the normal recovery effects. Sufficient differences between the two periods were found to assure the experimenter of the fact that fatigue effects would be felt in the second work period.

After this introductory series of ten pairs of performances (for both the arm and the leg) was completed, each subject ran through a series of five standard work problems on the lightest weight combinations. This resulted in a series of arm records taken from an initial exercise on the ten-pound weight, followed by a two-minute rest; then exercise on the standard fifteen-pound weight. For the leg, a thirty-pound, two-minute rest, thirty-five-pound standard combination, was used in this series. With the exception of the experimenter, Subject D, the subjects did not know that these groups were practise experiments.

From these series, the subjects went immediately into the problem proper. A practise control was also present in the arrangement of tasks. Comparisons between the rest periods, and the effects of incentive over non-incentive were desired for each weight combination. It was obvious that one long combination series could not be entirely completed and then be followed by the other comparative condition; for any resulting difference in the second series might not result from any intrinsic difference but merely from the practise effects. To avoid this, the following scheme was employed in the spacing of operations. On the first day, the subject would be required to follow the ten-pound, non-incentive, two-minute rest, fifteen-pound standard conditions. The same relative procedure would be employed for the leg experiment that same day, with the thirty-pound, non-incentive, two-minute rest, thirty-five-pound standard combination. The next day, the same combination as above would be used, with the exception that, instead of a two-minute rest, a four-minute rest would be interspersed between the two tasks. On the third day, the same combination as the first would be employed except that for the first working period the subject would be compelled to compete with the first period record of the first day; urged to exceed the designated goal. For the fourth day, the procedure would be the same as the second day, with incentive introduced in the first work period the same as on the third day, but with the different rest period. As comparisons

between the rests could now be made on records only one day separated, and as the same was true on comparison between the effects of incentive as of non-incentive performance, it seemed safe to believe that no great practise differences would assert themselves in this forty-eight-hour interval.

The fifth, sixth, seventh and eight days would be a repetition of the first four, as would also the ninth, tenth, eleventh and twelfth. The thirteenth to sixteenth (inclusive), and the seventeenth to twentieth, and the twenty-first to twenty-fourth would vary in that the weight in the first work period for the arm would be fifteen pounds instead of ten, and for the leg, thirty-five pounds instead of thirty. The rests and arrangement of incentive were the same.

The twenty-fifth to the twenty-eighth (inclusive), the twenty-ninth to thirty-second, and the thirty-third to the thirty-sixth performances differed in that the weight for the first work period for the arm was twenty pounds, and for the leg, forty pounds. The second work period was always the same as in previous performances. The distribution of rest periods, and the manner of introduction of incentive was as arranged before.

As has been stated, this would furnish us with thirty-six pairs of daily records from both the right arm and the right leg of each subject. In gathering this amount of data, one very striking fact was noticed. The subject almost always exceeded his former record whenever incentive was introduced, regardless of any minor variations that might have appeared in the original non-incentive series. The question arose as to whether or not there might not be even a further degree of attainment available from the subject, and if so, would it also show its corresponding effects on the second work curve? The manner of self competition with results visible had so far worked admirably as an incentive, so no special reason for introducing a new method was apparent. To obtain a new goal, however, the experimenter set as a limit for each subject to reach in the incentive first period series, a mark that was one-fourth farther removed (in terms of lateral distance on the drum) than the best record made previously by that subject in that specific weight in the non-incentive group. This accounted for individual differences. Here again the limit was set by a horizontal line, or end-mark,

on the drum which the subject attempted to surpass or attain. This was possible through the fact that by keeping time with the metronome the strokes were approximately equally spaced. Oftentimes in the case of the arm records, where the work with incentive only reached the mark designated, the subject nevertheless had surpassed the quantity of his former record by keeping the heights of the strokes more uniform, i.e., the drop in the line made by the tops of the individual strokes was less graduated over the whole series. This extreme goal was found to serve as an incentive even when the subject failed to reach it. His aim appeared to be an attempt to add another stroke to the lateral series in order to reduce by that much the distance to the goal. In other words, his purpose was a linear one rather than one of volume.

In this extreme competition series, the same combinations of weights and rest periods were used. Eighteen pairs of records (the second work period being controlled as above) were taken.

The next question arising was, if the effects of extreme exertion could be found to be visible in decreased proficiency in the second work period, would it not be logical to assume that lessened activity in the first work period might not cause heightened proficiency in the second? This was attempted by stopping the subject, during the first work period, at a point one-quarter distance, in terms of number of strokes, whether full or partial, from the lowest record made by him in the non-incentive group. This method required counting by the experimenter, the subject merely being told to stop at the point of desired cessation.

This series also furnished us with eighteen pairs of records, the same combinations of weights and rests being employed here as at earlier times. The same arrangements as to daily performances were used in the extreme competition and the series where the record was stopped as was employed in the two series of non-incentive and incentive groups. The record-stopped, two-minute rest, with standard second task following, done on one day; the extreme competition, two-minute rest, with second standard task following, done on the second day; record-stopped, four-minute rest, second task standard, for the third day; extreme competition, four-minute rest,

second task standard, for the fourth day. The whole series was repeated twice, as three records were taken for each of the three weight combinations, with the two rest intervals.

This second group of thirty-six records cannot be compared directly with the first group of records without recognition being made that practise has entered in. This means that the first record of the extreme incentive group (record number thirty-eight) is not greater than record number one of the voluntary exhaustion group without incentive because of that incentive difference alone. Practise has assuredly set in. But we may assume just as correctly that practise has influenced the second work periods proportionately, and if we do find that even with practise there is still a difference antithetical to that usually attributed to practise, we certainly are justified in recognizing that difference, and theoretically observing that the difference would have been greater if the practise factor could have been eliminated.

CHAPTER III

Results and Interpretation

The actual work program of each subject, carried out during the entire experiment, consisted of series of paired work periods; each pair divided by a rest interval. One series was made on the right arm, in the morning. A somewhat corresponding task was performed by the subject with his right leg in the late afternoon. The total number of daily paired work periods obtained from the arm from any one subject, was seventy-two. The same number of performances was obtained from the right leg. Both of these series were preceded by two respective practise groups of ten and five double performances.

As has been shown in the previous chapter, a special order of participation was followed in order to avoid any concerted effects of practise or transfer upon any one variable. Slight irregularities in attendance caused minor variation in progress during the program, although in general the four subjects worked on the same group of tasks at the same time. The records were numbered according to their classification, with the letters A, B, C, and D identifying the work of the respective subjects.

It was found that a millimeter on the smoked drum represented 0.017 meters of vertical displacement of the weights. By multiplying this unit by the weights themselves, in terms of kilograms, we have the work unit for each weight combination. This unit is expressed as kilogram-meter unit, or kgm. By measuring the total lengths of strokes recorded on the drum for any one record, in terms of millimeters, and multiplying this by kilogram-meter unit, we have a comparative work product for all records. The units for the respective weights are as follows:

10	lb.	weight	(4.55	kg.)	...	.077	kgm.	units
15	"	"	(6.82	")	...	.116	"	"
20	"	"	(9.09	")	...	.155	"	"
25	"	"	(11.38	")	...	.193	"	"
30	"	"	(13.64	")	...	.232	"	"
35	"	"	(15.91	")	...	.270	"	"
40	"	"	(18.18	")	...	.313	"	"

The first practise series of ten paired work periods is of very little importance as far as definite relationship with later experiments is concerned. This is due to the fact that this series employed in some of the combinations a repetition of the first-period weight in the second period in order to check upon the endurance of the fatigue effects. As a result, this differed from our main body of performances which kept the second work period constant with the fifteen- and thirty-five-pound weights respectively.

Several interesting things appeared during this first practise series. It was found that in the case of three of the subjects it was necessary for them to learn to keep in time with the metronome beats. The large records in the first work periods of the practise periods of Subject B were due to unintentional rest periods being introduced in the performance. This first group of tests also allowed the subjects to become somewhat familiar with the general routine of the process, so that any disturbances in that line would be eliminated. In some cases it was an entirely new experience to be compelled to continue a task to the point where exhaustion was evident. Where this was the case, the subject actually had to learn to become exhausted. The aches and pains resulting from this novel exertion were recovered from by the time the second practise series of five appeared.

The second series of five experiments performed under the standard conditions may be compared with similar combina-

TABLE I

SECOND PRACTISE SERIES (Kgms.) ARM

	Subject A		*Subject B*		*Subject C*		*Subject D*	
	Work	*Periods*	*Work*	*Periods*	*Work*	*Periods*	*Work*	*Periods*
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
10 lb. 2 min.	86	45	76	28	128	60	212	74
Non-	93	53	75	38	141	66	227	72
Incentive	104	52	71	47	151	62	231	72
	95	61	87	40	158	67	219	86
	114	62	110	41	169	57	246	85
SECOND PRACTISE SERIES (Kgms.) LEG								
30 lb. 2 min.	538	322	1234	414	1418	469	2839	773
Non-	582	303	1177	398	1332	474	2283	852
Incentive	641	360	1510	404	1586	501	2935	518
	624	490	1406	528	1471	575	3089	1074
	651	413	1614	521	1658	550	3619	1032

tions of factors found in the main experiment. A learning or practise tendency is manifest. The first rapid rise found in the repetition of any complex situation was accounted for in these two introductory series, which extended over a period of practically a month. Practise, naturally, continued during the experiment[1] but the assumption may be made that the first rapid rise has been passed over, and that the experiment was performed on a slowly rising level.

Looking at the range in this series for each subject, we see that the practise effect in quantity (expressed in kgms. of work) is larger in the first period than in the second. This would apparently show that the practise effects appear more obviously upon an untired muscle group than upon the same group when reduced to a common denominator through fatigue or exercise. Too few checks are available from this series, however, and other than mentioning that interpretation for this difference in these results, no more elaborate statement can be made.

Table II gives the sums obtained from the arm experiments in kilogram-meter units for each subject respectively, for the entire series of seventy-two paired performances.

Table III gives the results obtained (totals for the three trials of each combination) from the leg experiments in kilogram-meter units for each subject respectively for the entire series of seventy-two paired performances.

All records were originally expressed, as above, in kilogram-meters. However, when the individual differences between the subjects were noted, it was obvious that no grouping of the records could be made while the range of one combination of factors was as great as it turned out to be. For example, in the leg experiments Subject A has a total of 3372 kilogram-meters for the three records, numbers thirty-nine, forty-three, and forty-seven. For those same experiments, Subject D has a total of 15,270 kilogram-meters. Now, it has been stated that throughout the entire experiment the second work period was performed upon a standard weight (fifteen pounds for the arm, and thirty-five for the leg) and under standard conditions. Furthermore, the second one of the work combinations has as its first-work-period weight the

[1] Mosso gives us evidence of change in performance throughout a period of two years (*Fatigue*, Putnam, 1915).

same as is employed in the second work period throughout. We can say, then, that the first-work-period results of this respective combination show the amount of work that could have been done in the second work period if no work had pre-

TABLE II

(In Kilogram-meters)
Sums of the three trials for each work-combination for each subject

LEG TOTALS

Weight First Work Period	*Rest*	*Column I Record Stopped Before Exhaustion*		*Column II Without Competition Results Hidden*		*Column III Competition (With Col. I) Results Visible*		*Column IV Competition with Extreme Goal Visible*	
		Work Periods		*Work Periods*		*Work Periods*		*Work Periods*	
		1	2	1	2	1	2	1	2
Subject A									
30 lb.	2 min.	1154	1879	2166	1207	2217	1275	3372	1033
"	4 "	1164	2087	2045	1356	2489	1259	3429	1150
35 "	2 "	1146	1627	1500	1340	1645	1277	2212	1133
"	4 "	1300	1708	1721	1590	2147	1304	2262	1333
40 "	2 "	888	2055	1451	1328	1496	1276	1824	1188
"	4 "	900	2217	1441	1530	1816	1255	1953	1130
Subject B									
30 lb.	2 min.	3528	2753	5318	1660	5790	1526	12394	1382
"	4 "	3545	2962	5354	1823	6467	1777	12176	1493
35 "	2 "	1917	2932	2640	2155	3002	1896	4002	1670
"	4 "	1917	3266	2689	2276	3358	1992	3868	1871
40 "	2 "	1413	3469	2216	1780	2436	1688	3568	1459
"	4 "	1413	3706	2474	1909	2830	1713	3840	1585
Subject C									
30 lb.	2 min.	3030	3947	5368	1891	5363	1882	8961	1705
"	4 "	3030	4095	4831	2615	4782	2608	8987	1869
35 "	2 "	2505	3777	3927	2089	4089	2292	5133	1792
"	4 "	2481	4269	4216	2456	4883	2355	5444	1939
40 "	2 "	2367	3833	3418	2321	4053	2037	4969	1826
"	4 "	2367	4167	3463	2846	4010	2245	4934	2060
Subject D									
30 lb.	2 min.	7392	5317	10644	3049	11364	2574	15270	2482
"	4 "	7329	5707	11585	4634	12835	3781	15494	3405
35 "	2 "	4610	6061	6389	3590	8118	3190	10119	2837
"	4 "	4632	6262	6903	4328	8901	3723	11214	3606
40 "	2 "	3117	7236	4463	3944	4692	3728	6924	3523
"	4 "	3117	7635	4876	4709	5972	4604	7086	4078

ceded the second work period. As the first work period is not influenced by the amount of work that follows it, six records of this "standard" performance (from this second combination of experimental conditions) are available for both the arm and leg. By adding these six records and dividing

TABLE III

(In Kilogram-meters)

Sums of the three trials for each work-combination for each subject

ARM TOTALS

Weight First Work Period	*Rest*	*Column I Record Stopped Before Exhaustion*		*Column II Without Competition Results Hidden*		*Column III Competition (With Col. I) Results Visible*		*Column IV Competition with Extreme goal Visible*	
		Work Periods		*Work Periods*		*Work Periods*		*Work Periods*	
		1	2	1	2	1	2	1	2
Subject A									
10 lb.	2 min.	266	253	349	173	370	157	474	147
" "	4 "	270	275	349	259	410	232	417	197
15 "	2 "	218	276	288	240	310	195	379	145
" "	4 "	218	294	286	252	314	241	391	204
20 "	2 "	202	300	234	215	278	207	323	185
" "	4 "	204	349	235	258	282	231	329	200
Subject B									
10 lb.	2 min.	205	217	281	151	362	105	388	105
" "	4 "	205	242	277	196	384	179	417	164
15 "	2 "	150	251	206	147	231	136	279	122
" "	4 "	150	261	219	198	250	174	282	173
20 "	2 "	126	228	152	174	219	149	228	142
" "	4 "	126	232	154	223	192	191	236	182
Subject C									
10 lb.	2 min.	350	336	567	248	695	202	640	226
" "	4 "	351	376	563	304	632	267	785	266
15 "	2 "	267	328	410	258	478	185	465	218
" "	4 "	267	382	408	326	440	322	466	301
20 "	2 "	195	411	288	275	329	272	413	235
" "	4 "	195	432	325	324	364	321	381	306
Subject D									
10 lb.	2 min.	528	487	822	349	907	331	1038	298
" "	4 "	528	569	812	408	897	380	1214	350
15 "	2 "	264	550	523	342	604	333	632	322
" "	4 "	264	583	522	425	636	399	618	341
20 "	2 "	297	533	383	411	439	374	507	365
" "	4 "	297	548	382	444	450	433	500	426

by two, we have an averaged sum comparable to the sums of the three trials of the other combinations, and which may be taken as 100. All the other sums may then be expressed in its terms, i.e., per cent. This will give us a table of percentages based upon this "norm," and which will allow comparison not only of the work done by the respective subjects in any one weight combination, but also for the different weights. Tables IV and V express this in terms of the obtained percentages.

TABLE IV

Terms of % First Work Period, Column II, 15 pound weight

ARM TOTALS

Weight First Work Period	*Rest*	*Column I Record Stopped Before Exhaustion*		*Column II Without Competition Results Hidden*		*Column III Competition (With Col. II) Results Visible*		*Column IV Competition with Extreme Goal Visible*		
		Work Periods		*Work Periods*		*Work Periods*		*Work Periods*		
		1	2	1	2	1	2	1	2	
Subject A										
10 lb.	2 min.	93	89	122	61	129	55	166	51	
" "	4 "	94	96	122	91	143	81	146	69	Norm
15 "	2 "	76	96	100	84	108	68	133	51	287
" "	4 "	76	103	100	88	110	84	137	71	as
20 "	2 "	71	105	82	75	97	72	113	65	100
" "	4 "	71	122	82	90	99	81	115	70	
Subject B										
10 lb.	2 min.	96	102	132	71	170	49	182	49	
" "	4 "	96	114	130	92	180	85	196	77	Norm
15 lb.	2 "	70	117	97	69	108	64	131	56	212.5
" "	4 "	70	122	103	93	117	82	133	81	as
20 "	2 "	59	107	71	82	103	70	107	67	100
" "	4 "	59	109	72	104	90	89	111	86	
Subject C										
10 lb.	2 min.	86	82	138	61	169	49	156	55	
" "	4 "	86	91	137	74	154	65	191	65	Norm
15 "	2 "	65	80	100	63	117	45	113	53	409
" "	4 "	65	93	100	79	108	78	114	74	as
20 "	2 "	48	100	70	67	80	66	101	57	100
" "	4 "	48	106	79	79	89	78	93	75	
Subject D										
10 lb.	2 min.	100	93	156	66	172	63	197	57	
" "	4 "	100	108	154	77	170	72	231	66	Norm
15 "	2 "	50	104	100	65	115	63	120	61	522.5
" "	4 "	50	111	100	81	121	76	117	65	as
20 "	2 "	56	101	73	78	83	71	96	69	100
" "	4 "	56	104	72	84	85	82	95	81	

As Tables II, III, IV and V are all arranged in the same manner, a description of one will suffice for all. In Column I we find the first and second work period data for those experiments where the record was stopped at a point one-quarter below the lowest exhaustion limit obtained in the non-incentive, performance-hidden group. In Column II, we have the first and second work period data for those experiments where the subject did his work without incentive, and with performance unrevealed. In Column III, we have the

TABLE V

In terms of % First Work Period, Column II, 35 pound weight

Weight First Work Period	*Rest*	*Column I Record Stopped Before Exhaustion*		*Column II Without Competition Results Hidden*		*Column III Competition (With Col. II) Results Visible*		*Column IV Competition with Extreme Goal Visible*		
		Work Periods		*Work Periods*		*Work Periods*			*Work Periods*	
		1	2	1	2	1	2	1	2	
Subject A										
30 lb.	2 min.	72	117	135	75	138	80	209	64	
" "	4 "	73	130	127	85	155	79	213	72	Norm
35 "	2 "	72	101	94	84	102	80	138	71	1610
" "	4 "	81	106	107	99	133	81	141	83	as
40 "	2 "	55	128	85	83	93	80	113	74	100
" "	4 "	56	138	85	95	113	78	121	71	
Subject B										
30 lb.	2 min.	132	103	200	62	217	57	460	52	
" "	4 "	133	111	201	68	243	67	457	56	Norm
35 "	2 "	72	110	99	81	113	71	150	63	2665
" "	4 "	72	122	101	85	126	75	145	70	as
40 "	2 "	53	130	83	67	91	63	134	55	100
" "	4 "	53	139	93	72	106	64	144	59	
Subject C										
30 lb.	2 min.	74	97	132	46	132	46	225	42	
" "	4 "	74	101	119	64	118	64	227	46	Norm
35 "	2 "	62	93	97	51	100	56	126	44	4072
" "	4 "	61	105	103	60	120	58	134	47	as
40 "	2 "	58	95	84	57	100	50	122	44	100
" "	4 "	58	103	85	70	99	55	121	51	
Subject D										
30 lb.	2 min.	111	80	160	46	170	39	229	37	
" "	4 "	110	86	179	70	193	57	232	51	Norm
35 "	2 "	69	91	96	54	122	48	152	43	6646
" "	4 "	69	94	104	65	134	56	168	54	as
40 "	2 "	47	109	67	59	70	56	104	53	100
" "	4 "	47	115	73	71	80	69	106	61	

first and second work period data for those experiments where the subject competed with the mark previously set by the non-incentive group (as shown by first work period, Column II). In column four, we have the first and second work period data for those experiments where the subject competed with a mark set at one-quarter the lateral distance beyond the farthest exhaustion point in the non-incentive, hidden-performance experiment (Column II). All of these records are divided up into the respective weight series employed, and also as to the extent of rest allowed between the first and second work periods. It must be emphasized that

the second work period in every case was the same, non-incentive; results unknown; standard weight; exhaustion limit.

As every employed combination has but three records for each subject, no averages were taken. The totals, either in kilogram-meters or in one-hundredths, serve as well, or better.

In looking at our results, several questions should be kept in mind. First, did the difference in time in the rest (two minutes as compared with four) bring about any consistent differences in the amount of work done in the second work period? Secondly, did the employment of different weights in the first work period cause any consistent or progressive differences to be found in the amount of work done in the first work period, and in the second work period? Another question,—did the influence of incentive as used here, cause greater amount of work to be produced in the first work period consistently? And following from that, if greater work was produced in the first work period, did this increase in effort leave any effects so that a decrease in output in the second work period would result? Did any consistent differences appear in the results obtained from the leg experiment as contrasted with the arm experiment? Furthermore, were there any noticeable individual differences in any of these points, among the subjects used? Was the variability, either in the records of each individual, or in the group, such that the efficacy of interpretating the data at hand would be impaired?

From the data as produced in Tables IV and V, the percentage tables, a series of graphs may be made, using the four types of work combinations (the four ways in which the first work period limit was obtained) as the base line, and a percentage scale (carried to extremely high limits) as the vertical axis. By adding together the totals of the three trials of each subject for each combination, we may obtain a grand total for the four subjects, for each combination.

The composite graphs, Figures III and IV, result from this collection of data, showing the first and second work periods for the four subjects (in terms of the arbitrary norm assigned above, i.e., percentage) for the four work variations (see p. 40-41 above).

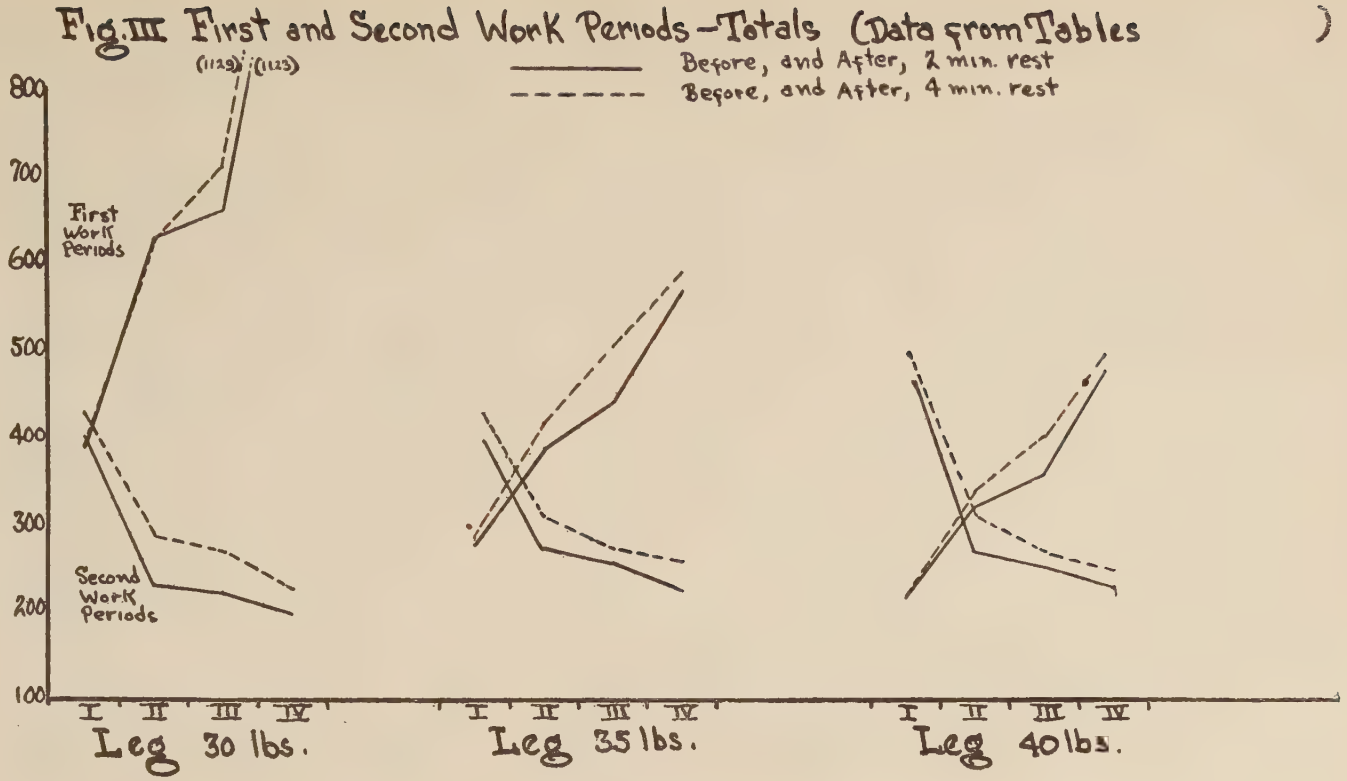
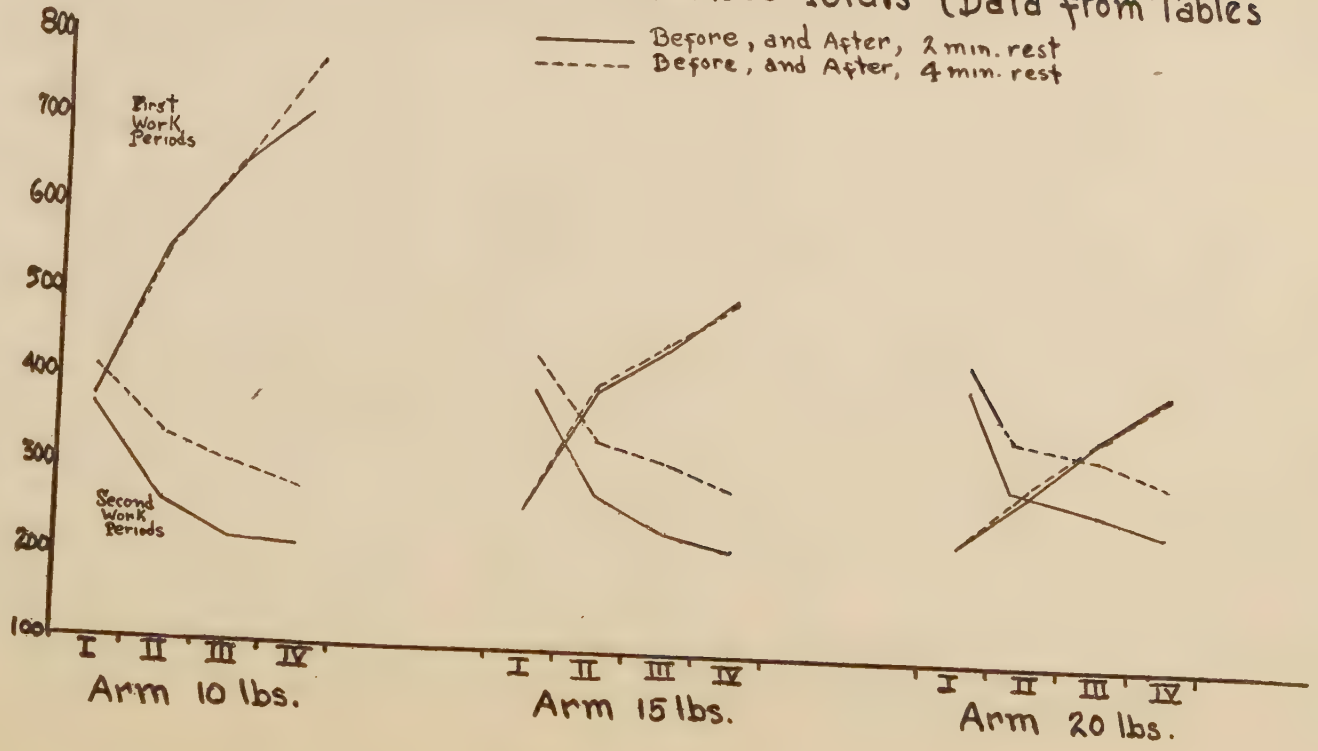


Fig. III First and Second Work Periods – Totals (Data from Tables)
Before, and After, 2 min. rest
Before, and After, 4 min. rest
(1129)
(1123)
800
700
600
500
400
300
200
100
First Work Periods
Second Work Periods
I II III IV
Leg 30 lbs.
Leg 35 lbs.
Leg 40 lbs.

Fig. IV First and Second Work Periods - Totals (Data from Tables)



This arrangement immediately allows for comparison of the various combinations. On any one graph we may see the effects of two- *versus* four-minute rest periods; variations as to the amount of work done in the first work period; whether or not incentive, as employed, does cause increase in amount of work in the first work period; whether this increase in the effort during the work period does not evidence itself in changes in the second work period; variations in the group (for any one series); and general tendencies.

When we look at the entire group of graphs, we are aware of a great similarity existing between them, especially in the common dependence on the part of the second work period upon the amount of work produced in the first work period. This dependence is manifest regardless of whether a four-minute rest was used instead of a two-minute period. This phenomenon, seemingly so obvious, yet actually a point ignored in industrial management material, and fallaciously contradicted in the article referred to above,[2] has developed as the most striking factor in our investigation. In order to bring out this point more clearly, and in statistical terms, the product-moment coefficient of correlation[3] between the first and second work periods of each weight-rest combination was figured. Negative coefficients or correlation of a high order were found. These are expressed as follows:

Correlation Between First and Second Periods
Taken from individual scores for each subject. N = 48

First Work Per.	*Rest*	*Second Work Per.*	"r"
Arm—10 lb.	2 min. rest	15 lb.	—.81
Arm—10 lb.	4 " "	15 lb.	—.51
Arm—10 lb.	2 " "	15 lb.	—.90
Arm—15 lb.	4 " "	15 lb.	—.57
Arm—20 lb.	2 " "	15 lb.	—.88
Arm—20 lb.	4 " "	15 lb.	—.68
Leg —30 lb.	2 " "	35 lb.	—.46
Leg —30 lb.	4 " "	35 lb.	—.65
Leg —35 lb.	2 " "	35 lb.	—.54
Leg —35 lb.	4 " "	35 lb.	—.47
Leg —40 lb.	2 " "	35 lb.	—.71
Leg —40 lb.	4 " "	35 lb.	—.84

[2] Wright, W., op. cit.

[3] Garrett, H. E., *Statistics in Psychology and Education*, Chapters IV and V, 1926.

The arm series show a marked phenomenon in the lowered negative correlation in the four-minute rest series. Apparently the four-minute rest allows the second work period to smooth out, or approach a horizontal line, which is not found so clearly in the second work period after the two-minute rest. In other words, the tendency for the two curves to separate is checked somewhat by the increased rest period. One could obviously state that with no matter how great a strain exerted in the first period, more rest interval will eliminate the effects. If further investigation is made upon this distinct separation tendency, or negative correlation between output in the first and output in the second period, certainly no greater rest period should be used; and, in all probability, even a still further shortening of the recuperation time would be beneficial.

In the leg series, this four- *versus* two-minute rest period is not so progressively shown. However, in the leg series we find such an extreme progression in the amount of work done in the first work periods, with no such marked decline found in the second work periods, that our correlation is influenced. This is further development of the observation made upon our original practise series, where it was noticed that the effects of practise are more pronounced in the fresh muscle group than upon the fatigued group. The large jump in the fourth series (extreme competition) must be explained more because of practise than through heightened susceptibility to the competition suggestion. The drop in the second work curve, for this group, is remarkable in that it appears at all. It must be of pronounced existence or it would have been entirely smothered out through the learning (strengthening and habituation) factor during the extended experiment.

Figures V and VI show graphically, but in a different manner, the dependence of the second work period upon the first, for each specific weight of the arm and the leg experiments. Curves are roughly fitted; the two heavier weights combined in Figures VIII and IX (Arm).

Using the second work period for the vertical axis, and the first work period for the horizontal axis, the distribution of the data, as shown by the curves, allows comparisons to be made for the different weights. The light weights extend much farther horizontally, signifying that more work is ac-

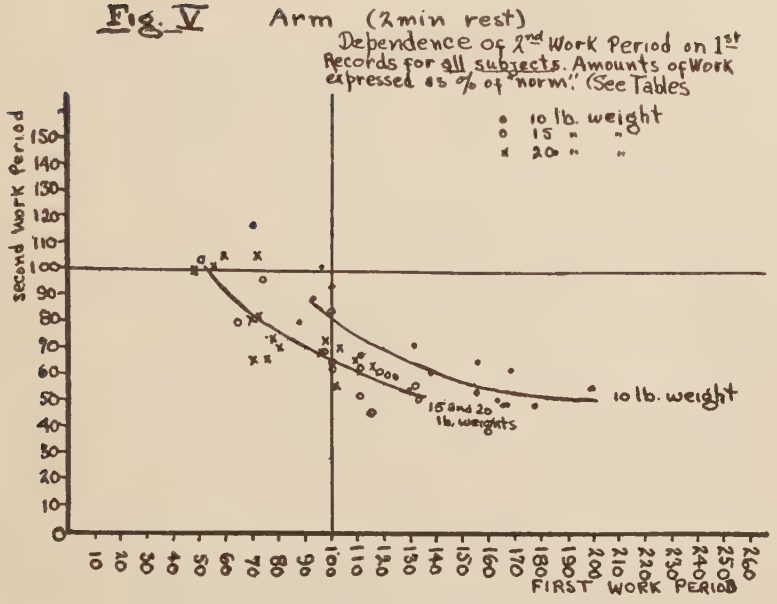


Fig. V
Arm (2 min rest)
Dependence of 2nd Work Period on 1st
Records for all subjects. Amounts of Work
expressed as % of "norm." (See Tables
• 10 lb. weight
o 15 " "
× 20 " "
Second Work Period
10 lb. weight
15 and 20 lb. weights
FIRST WORK PERIOD

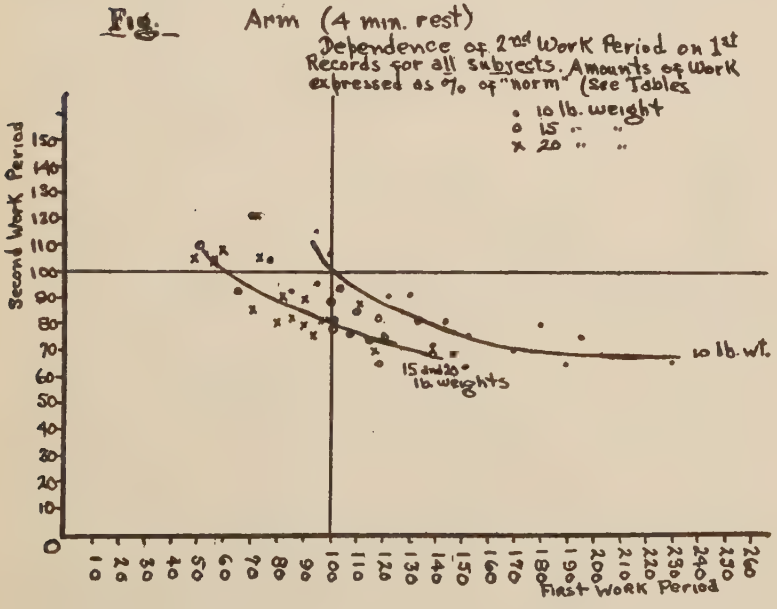


Fig.
Arm (4 min. rest)
Dependence of 2nd Work Period on 1st
Records for all subjects. Amounts of Work
expressed as % of "norm" (See Tables
• 10 lb. weight
o 15 " "
× 20 " "
Second Work Period
10 lb. wt.
15 and 20 lb. weights
First Work Period

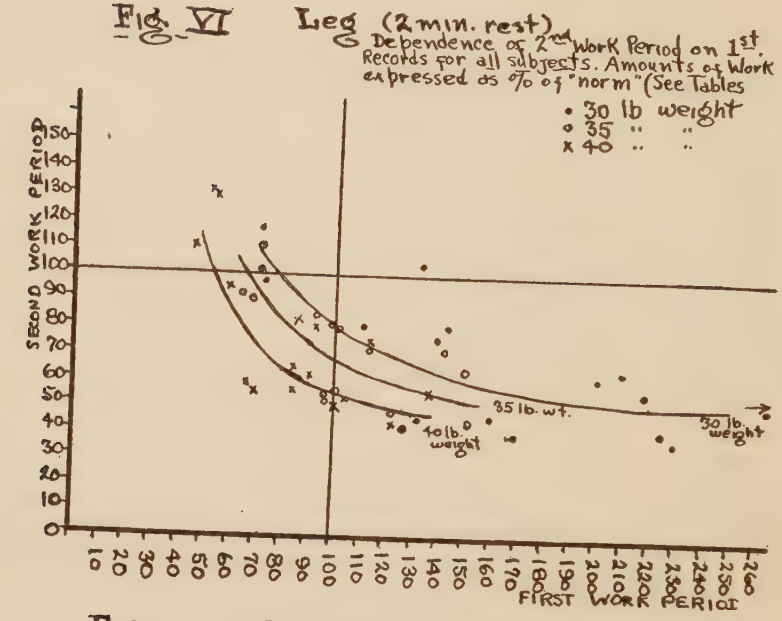


Fig. VI Leg (2 min. rest)
Dependence of 2nd Work Period on 1st.
Records for all subjects. Amounts of Work
expressed as % of "norm" (See Tables
• 30 lb weight
○ 35 " "
× 40 " "
SECOND WORK PERIOD
35 lb. wt.
40 lb. weight
30 lb. weight
FIRST WORK PERIOD

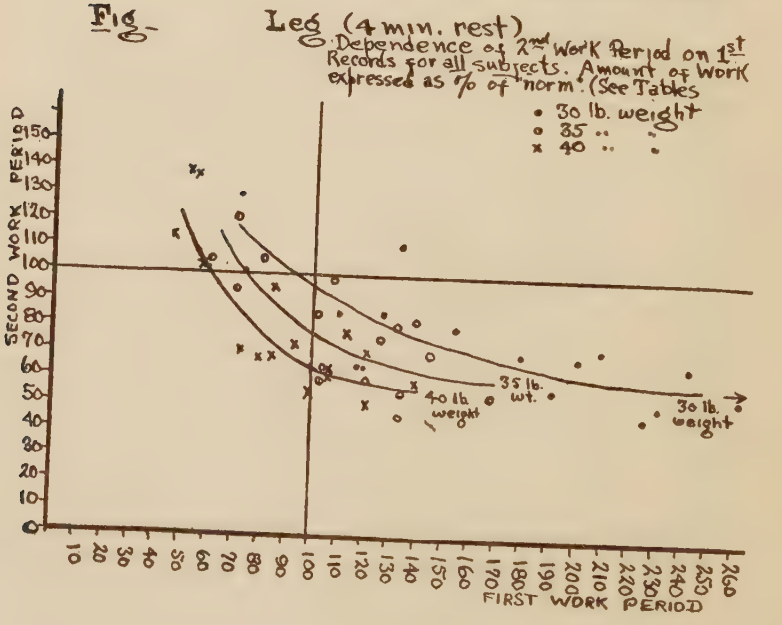


Fig. Leg (4 min. rest)
Dependence of 2nd Work Period on 1st
Records for all subjects. Amount of Work
expressed as % of "norm." (See Tables
• 30 lb. weight
○ 35 " "
× 40 " "
SECOND WORK PERIOD
35 lb. wt.
40 lb. weight
30 lb. weight
FIRST WORK PERIOD

complished in the first work period with the light weights than with the heavy. The obvious antithesis of this is seen in the greater number of cases of heavyweight distribution at the left side of the graphs, and by the short extent of the curves for the heavy weights. This shows that less work is accomplished with the heavy weights in the first work period than with the light weights. When we look at the vertical distribution, we find (glancing at the extremes) an inverse relation between the amounts of work done in the first work periods and that done in the second. This has been stated before in terms of negative correlation (Page 45). Even if we disregard the size of the weights, the axiom holds true, that the greater the amount of work done in the first period, the smaller the amount of work done in the second.

We cannot actually compare the extremes, for there is no overlapping of the weight curves at those points. However, where the records fall in the same general area of the first work period performance, interesting distinctions between the weights are observed. The curve for the light weight lies higher than those for the heavier weights. This allows the assertion that given approximately the same amount of work in the first period (as shown by extension on the horizontal axis) more work will be accomplished in the second work period which follows a light weight, than when following a weight as heavy or heavier than the one used in the standard second work period. Similar quantity of work does not at all assure the same amount of muscular tension. The rate of onset of fatigue is more rapid, in proportion, for the heavy weights than for the light weights. Hence, a point of output on the performance curve for the respective weights which may be quantitatively the same, nevertheless may signify entirely different degrees of fatigue; and as a result will leave varying work effects to be exhibited in the second work period. This would account for the greater amount of second period work in the performance where the standard follows a lighter weight.

Some of our questions are definitely answered. Incentive, in this case self-competition, and visible performance, most positively produced greater amount of work on the part of the subject. A comparison of the first work periods of columns two and three show this factor in controlled condi-

tions. A glance at the first work period of Column IV also shows this effect to a most high degree, but the extreme difference as found here must be partly accounted for by practice effects. Everyone of the subjects showed this influence of incentive in all the tasks as set by this experiment.

Secondly, with this extra exertion on the part of the subject in the competition series, a noticeable effect on the standard second-work period was shown by a decrease in output corresponding to the increase in output in the first series (mathematically expressed by our correlation tables) and graphically expressed by Figures III, IV, V and VI. Although this was not at all a one-to-one relationship, the tendency was so pronounced that this conclusion may be safely accepted.

Interesting individual records seemingly verify this assertion, as a glance at the tables will show. With recognition of the fact that the exhaustion point in these voluntary fatigue experiments is rather a fluctuating standard, not only among subjects but even in the series of records for any one subject, a striking drop in first work period activity would probably be more safely explained through some other factor than mere muscular exhaustion; especially since we find a logical (based on our above assumptions) increase in the second work period that is out of proportion to the other of the series. It is just from such an increase as this that the desirability of having a controlled second work period throughout the experiment is manifest. In general, however, it is obvious that a most high degree of regularity was present in the repeated attempts to go to exhaustion. If any criticism on the procedure might be given, the most glaring one that developed was that the thirty-pound weight was too light for obtaining a convenient work curve: two of the subjects were able to go completely around the drum in the visible results series. A task that required approximately fifteen minutes for accomplishment, with the procedure so uniform and the onset of fatigue was so gradual, naturally carried with it factors (such as boredom) very hard to ignore.

As for the effects of the varied rest periods, a noticeable consequence was apparent. Although there were individual records that indicated as high a degree of recovery in the two-minute rest period as in the four, the general tendency as shown by the totals, and by the great majority of the in-

dividual records, was distinctly in the expected direction whereby more work in the second work period was produced after a four-minute rest than after a two-minute one. The difference between the two rest periods was noticed by all the subjects, so naturally some degree of auto-suggestion might have been introduced by the logical assumption that more rest should mean more recovery; hence more work later on. Whatever the motivation, our results distinctly show that the four-minute rest period allowed for greater recovery, as shown by more work in the second period. This is graphically shown in the above figures, where the second work period curve, after the four-minute rest, remains above the second work period curve after the two-minute rest in all four of the controlled situations. From this same observation another interesting point seems apparent in the case of the arm experiments. The difference in recovery effects is greatest when the preceding work period has been of most severe exertions. The leg experiments do not show this as clearly, although even here we find a progressive difference in the case where the subject is stopped before the exhaustion point and the situation of competing with a former record. Due to the nature of the situations, however, the author believes that the records obtained from the arm are freer from uncontrollable irregularities than those of the leg; hence the above conclusions are tendered.

The question pertaining to the effects of the employment of different weights in the first task has interesting connections. By looking at our data, we observe that the amount of work in the first part of each performance pair decreases as the weights increase in difficulty. This is in accord with the expression of Muscio,[4] who states that more work can be produced by a muscle group, when a light weight is employed than when a heavy one is being lifted. On the standard second period a related tendency is evident, for while the subject exerts more work with the lighter weights, in the first period, less work is produced in the second work period following. This last statement is not at all universally evident in our data, but it is most clearly shown in the extreme competition series, and also easily traced throughout the other series where exhaustion is approximated at first. This may be ex-

[4] Muscio, B., *Lectures on Industrial Psychology*, Chap. II, 1920.

plained not only by our cause and effect relationship, as outlined in other circumstances, but also through a phenomenon long ago pointed out by Treves[5] and others. When a muscle group, or excised muscle, is exhausted for one task (a certain weight), if some of that weight is removed, the muscle can go on responding. By continually removing fractions of the weight, a closer approximation to absolute exhaustion is reached.

Referring to Howell's Textbook of Physiology[6], we find when "the muscle is supposed to contract against a constant load which it can lift, such a contraction is spoken of as an isotonic contraction. A portion of the energy liberated in the muscle by the stimulus is converted into mechanical work of lifting the load. If the muscle is allowed to contract against a resistance too great for it to overcome, it is practically prevented from shortening, and a contraction of this kind, in which the length of the muscle remains unchanged, is spoken of as an isometric contraction..... In this case mechanical work, in the sense of lifting a load, is prevented and the portion of the liberated energy which would have taken this form in the isotonic contraction now serves to develop a state of elastic tension in the muscle; the course of the isometric contraction gives graphic representation of the rise and fall of this state of elastic tension."

There can be a muscle group fatigued then for a certain tension, and still be comparatively able to produce work calling for "lesser" tension. This is what occurs in the case of continuing the work curve (apparently at the point of exhaustion) by reducing the size of the task (removing weights, etc.). It has even been stated that suggestion as to subtracted or added weights has at times caused the resulting work curve to be influenced.[7] It is obvious that the ergograph in the weight form does not enable us to measure the total amount of work that the muscle is capable of performing. When the point of complete fatigue is reached, with any one task, the muscle is still capable of doing work, i.e., external work, if we replace the heavy load by a lighter one.

Although with no such aim in mind, the same relative procedure was employed in this experiment. By introducing the

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[5] Treves, Z., *op. cit.*, 1901.
[6] Howell, W. H., *Text-book of Physiology* (8th. ed.) p. 28.
[7] Fox, C., *Educational Psychology*, Chap. XII, p. 327.

rest period of such duration a great deal of the shock in the perceived difference in weight was naturally lost. However, by having the subject change from a thirty-pound weight to a thirty-five-pound weight, and inversely from a forty-pound weight to a thirty-five, or from a twenty-pound weight to a fifteen, the above effect was introduced. Furthermore, it was impossible for the subject not to know that a change had been made. It is interesting to see that the effects are found even under these conditions of gross muscular work interspersed by longer rest periods.

Differences between the leg and the arm experiment are more on the order of quantity than of intrinsic peculiarities. The most striking difference in the type of curve produced by the leg performance as contrasted with the arm performance has already been dealt with. And as far as recovery percentages are concerned, each subject seems to show similar recovery in terms of percent of the first work period for the leg task and for the arm. Certain differences are noted, but these are smoothed out as the various series are studied. The greatest exception is in the case of the lighter weights,—touched upon in the discussion of effects of varying the weights in the first work period. In this group, the fatigue effects seem to be more pronounced in the leg experiments than in those for the arm. This applies especially to subjects B and C. All the subjects noted that different "feel" of the extreme fatigue of the leg, as compared with that of the arm. The strain in the arm seemed more localized and real, while that of the leg was more widespread throughout that organ. If anything can be based upon such asserted sensibilities, then the leg experiments did effect the organism more generally and in such a way that the fatigue effects were more enduring. Here again the reported recovery effects for the heavy weights seemed more rapid than for those of the light weights.

As far as the individual differences among the subjects were concerned, the amount and character of work clearly showed that the four subjects varied greatly in capacity. The low degree of output of Subject A in the leg experiment has already been discussed. In the arm experiment, he suffered no such handicap and a comparable amount of work was produced. In order of amount of work done in the arm experi-

ment, the subjects were in the following low to high order: B; A; C; D. In the leg experiment, A; B; C; D. With the exception of Subject IV (who had previously been a subject for a somewhat similar experiment three years previous) it would appear that a person's superiority in one type of exercise (leg *vs.* arm) did not necessarily hold for others. This is an obvious fact observable in any class of physical training. On the other hand, if a larger scale could be employed, and a general fatigue resistance quotient be obtained, the four subjects might possibly fall in the following order: A; B; C; D.

In looking at the totals of the non-incentive series as compared with the incentive, no great differences between the four subjects are observable. All four were able to exceed their former work record, and in terms that depended more on the length of the previous non-incentive work record rather than upon any individual difference in suggestibility. The results of subject D seemed to indicate a more general and regular progression under the various situations, but this in itself is not comparable to the other three taken as a group.

Figures VII, VIII, IX and X show the scores obtained from Tables IV and V, of the four subjects in relation to their respective recovery abilities, as expressed by the relation of the work done in the second period to that done in the first. A median curve was roughly fitted. This enables each subject to be located in respect to the median recovery ability. Individual variations are apparent. In the Arm experiment, two-minute rest (Figure VII), Subjects B and D have as many records above the median line as below, and as a result may be considered more or less average scores. Subject A, however, has eight scores above the median line, and only four below, which may mean that the recovery process for this subject is far more rapid than for the others. Subject C is the opposite type, with three records above and nine below; which, in terms of recovery may be interpreted as showing a slow rate of recovery.

In the Arm experiment, four-minute rest (Figure VIII), Subject A and Subject B both show rapid recovery, with eight above and four below the median for Subject A, and twelve above and none below for Subject B. Subjects C and D are of the opposite type, apparently slow in recovery. Sub-

Fig. VII

Arm (2 min. rest)
Dependence of 2nd work period on 1st in relation to Subjects' recovery abilities.
Records for each Subject taken from Table where amounts of work are expressed in terms of % of "norm".

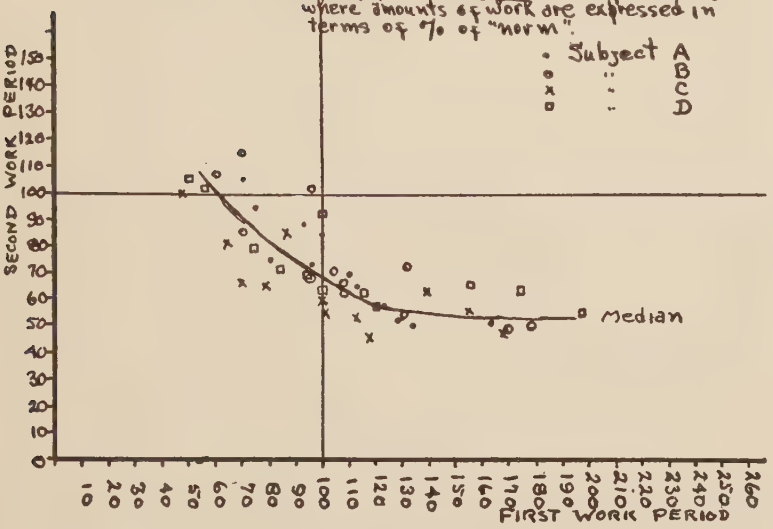


Fig. VIII

Arm (4 min. rest)
Dependence of 2nd work period on 1st. in relation to Subjects' recovery abilities.
Records for each Subject taken from Table where amounts of work are expressed in terms of % of "norm".

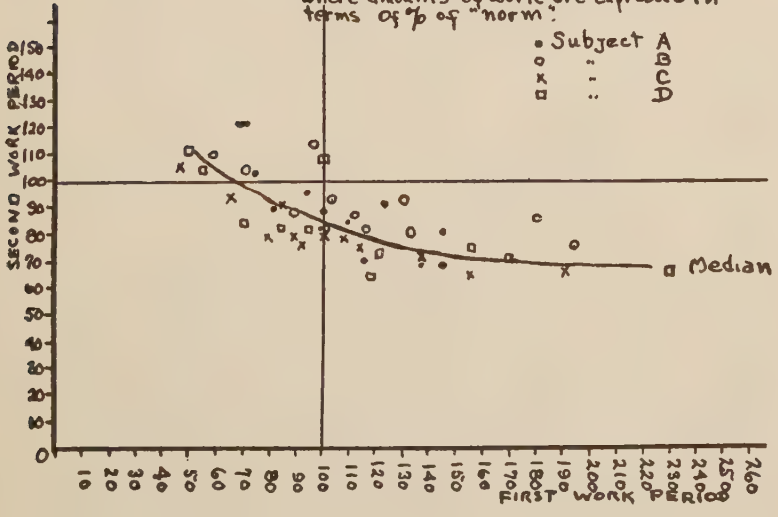


Fig. IX Leg (2 min. rest)
Dependence of 2nd work period on 1st. in relation to Subjects' recovery abilities
Records for each Subject taken from Table where amounts of work are expressed in terms of % of "norm"

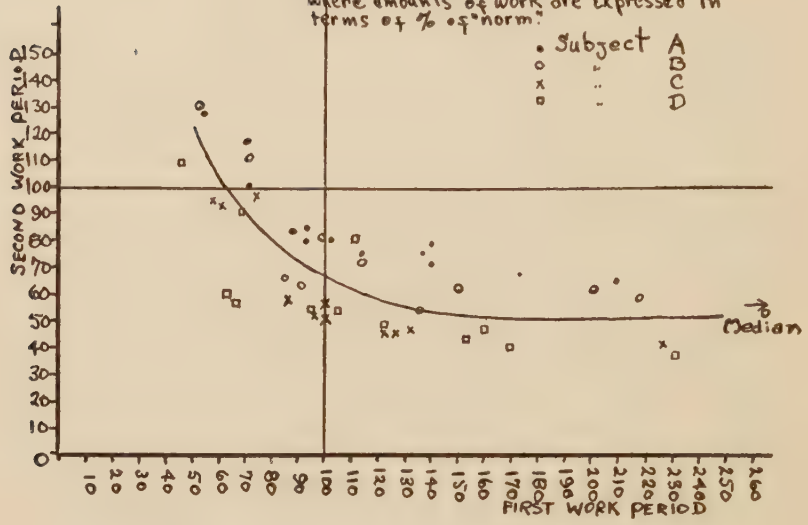
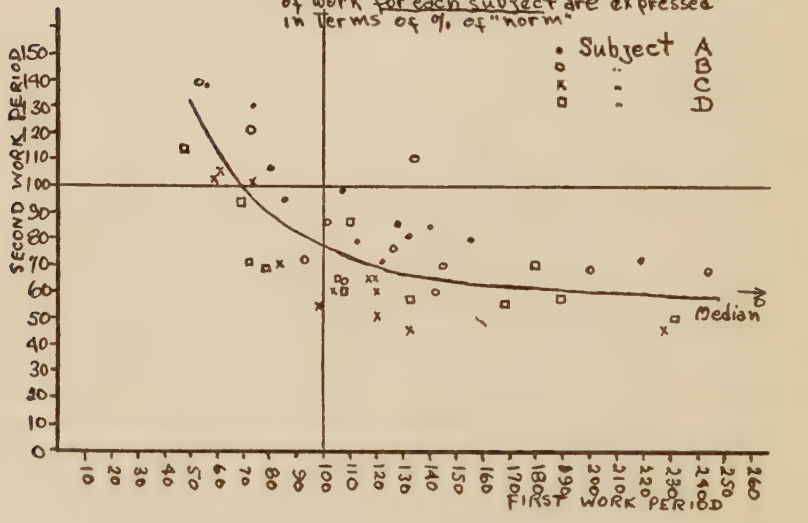


Fig. X Leg (4 min. rest)
Dependence of 2nd work period on 1st in relation to Subjects' recovery Abilities
Records taken from Table where amounts of work for each subject are expressed in terms of % of "norm"



ject C has two records above the median line, and ten below. Subject D, four above and eight below.

In the leg experiments, as expressed by Figures IX and X, this last division of subjects is more strikingly expressed. In Figure IX, Subjects A and B both demonstrate rapid recovery, A having all twelve records above the line; B having nine above and three below. Subject C and Subject D each have eleven below this median line, and only one above, showing apparently slow recovery. In the four-minute rest series (Figure X), this same relation is developed further, Subject B having nine above and three below. Subjects C and D again demonstrate slow recovery, Subject C having only one record above the median line and eleven below, and Subject D having only two above and ten below.

A more personal explanation for the above differences may be offered, although any verification for this assumption would be difficult to obtain other than from the very data for which the explanation is offered. Subject A admitted some inconvenience in using his right leg because of an old wound. Subject D, the experimenter, might have had more personal interest in the exactitude of method (i.e., been more insistent upon reaching an exhaustion point). Therefore, the differences between Subjects A and B, and C and D might possibly be due to the fact that in the first work periods respectively, the last two subjects actually approached the maximum performance point more closely than did the first two subjects. Therefore, the slower rate of recovery (in comparison with the other two subjects) might be due to greater exertion (in proportion) having been expended in the first work periods.

The differences between the four subjects in this respect should be accounted for by both hypotheses, since no exact statistical interpretation is possible. Whether due to organic differences, which allow for variability in the capacity to recover from work, or whether due to more "human" causes, such as a hesitancy towards working to exhaustion, nevertheless we see an existing difference, however small, in the performances of the four subjects, under these experimental conditions.

To appreciate any variability, a greater number of cases than three of any specific combination would have to be em-

ployed. From our data, the only possible trend would be that there appears a reduction in variability on the part of any one subject as the weights increase, and as the exertion increases. However, this can by no means be made as a dogmatic assertion, for even under these circumstances too great deviations from this process are evident. The most positive note is in the increase of weights, which allows for less variability by any one subject. The variations in the second work period, for the whole series, show no motivation. The variability is as pronounced after a four-minute rest as after a two.

It is more to our interest to observe the lack of variance rather than its obviousness. In this very minimal amount of individual variation, for any one series, a good argument for the presence of effectively controlled conditions is furnished.

If we can think of a work performance as consisting of the two work periods, interspersed by a two- or a four-minute rest, it might also be of interest to consider how each task, or performance, taken as a whole, compares with the others. For example, to observe whether the incentive group (counting both first and second work periods) produces more work than when there is no incentive in the first. Stated in another way, will the increase through incentive in the first be cancelled by the decrease in the second work period?

Tables VI and VII show the four work performances arranged as before, but the first and second work periods are in this case added together, for each subject. This data was obtained from Tables IV and V, where the results are expressed in per cents of the sums of first work periods of the fifteen- and thirty-five-pound weights respectively. Adding the totals of the four subjects, we have four sums expressing the total amount of work produced under each of the four conditions of the experiment: record stopped, no incentive, competition with the no-incentive record, and extreme competition with a point beyond the best non-incentive record.

Looking at the sums for each weight under the different columnar headings, we see that there is a progressive decrease in total amount of work done as the size of the weights increases. With one exception, this apparently holds just as forcefuly when a four-minute rest is used as when a two-minute rest intervenes.

Comparing the four work conditions in terms of the total

work performed, we find a distinct progression from the condition where the record is stopped below the exhaustion point, towards the condition of extreme competition. The progression is most definite in the case of the light weights (for both

TABLE VI

Total Work Done in BOTH Work Periods. (Data from Tables IV and V In terms of % First Work Period; Column II, 15 lb. Weight.)

ARM TOTALS

Rest	*Subject*	*Column I Record Stopped Before Exhaustion*	*Column II Without Competition Results Hidden*	*Column III Competition (With Col. II) Results Visible*	*Column IV Competition with Extreme Goal Visible*
		10 lbs.	First Work Period		
2 min.	A	182	183	182	217
" "	B	198	203	219	231
" "	C	168	199	218	211
" "	D	193	222	235	254
		741	807	854	913
		15 lbs.	First Work Period		
" "	A	172	184	176	184
" "	B	187	166	172	187
" "	C	145	163	152	166
" "	D	154	165	178	181
		658	678	678	718
		20 lbs.	First Work Period		
" "	A	176	157	169	178
" "	B	166	153	173	174
" "	C	148	137	146	158
" "	D	157	151	154	165
		647	598	642	675
		10 lbs.	First Work Period		
4 min.	A	190	213	224	215
" "	B	210	222	265	273
" "	C	177	211	219	256
" "	D	208	231	242	297
		785	877	950	1041
		15 lbs.	First Work Period		
" "	A	179	188	194	208
" "	B	192	196	199	214
" "	C	158	179	186	188
" "	D	161	181	197	182
		690	744	776	892
		20 lbs.	First Work Period		
" "	A	193	272	180	185
" "	B	168	176	179	197
" "	C	154	158	167	168
" "	D	160	156	167	176
		675	762	693	726

TABLE VII

Total Work Done in BOTH Work Periods. (Data from Tables IV and V In Terms of % First Work Period; Column II, 35 lb. Weight.)

LEG TOTALS

Rest	*Subject*	*Column I Record Stopped Before Exhaustion*	*Column II Without Competition Results Hidden*	*Column III Competition (With Col. II) Results Visible*	*Column IV Competition with Extreme Goal Visible*
		30 lbs. First Work Period			
2 min.	A	189	210	218	273
" "	B	235	262	274	512
" "	C	171	178	178	267
" "	D	191	206	209	266
		786	856	879	1318
		35 lbs. First Work Period			
" "	A	173	178	182	209
" "	B	182	180	184	213
" "	C	155	148	156	170
" "	D	160	150	170	195
		670	656	692	787
		40 lbs. First Work Period			
" "	A	183	168	173	187
" "	B	183	150	154	179
" "	C	153	141	150	166
" "	D	156	126	126	157
		675	585	603	689
		30 lbs. First Work Period			
4 min.	A	203	212	234	285
" "	B	244	269	310	513
" "	C	175	183	182	273
" "	D	196	249	250	283
		818	913	976	1354
		35 lbx. First Work Period			
" "	A	187	206	214	224
" "	B	194	186	201	215
" "	C	166	163	178	181
" "	D	163	169	190	222
		710	724	783	842
		40 lbs. First Work Period			
" "	A	194	180	191	192
" "	B	192	165	170	203
" "	C	161	155	154	172
" "	D	162	144	149	167
		709	644	664	734

the leg and the arm experiments), for both rest periods. The progression is also apparent in the other weights employed; but we find that sometimes the totals in Column I, where the record is stopped, are greater than the totals of the non-incentive or the first competition series. It must be recalled that

this column is affected by practise, and also by the fact that the point of stopping may be low enough down the scale of the subject's possible capacity, that this first work period may serve as a "warming up" preliminary for the second work period. This last may only be ascertained by other investigations which set this stopping point at limits lower down the capacity scale than the one employed here.

CHAPTER IV

Conclusions and Summary

By developing the ergographic principle so that measurement could be made upon larger isolated groups of muscles, and by controlling the performance situation, we have investigated the effects of preliminary variations in work upon a standard task.

A double work period was used. In three series the first work period was varied by introducing different weights which were lifted by each subject to the point of exhaustion.[1] In the fourth series (Column I in the above Tables) this work period was stopped at a point well below the exhaustion point of each subject. When the specified work limit in these four series was reached, the subject was allowed to rest. The rest interval varied throughout the experiment, half of the records taken with a two-minute interval and half with a four. After the rest, the subject lifted a standard weight to the point of exhaustion. This second work period was kept constant throughout the entire experiment.

A further modification of the first work period in two of the series (Column III and IV in the Tables) was the introduction of incentive. This took the form of allowing the subject to see his performance as it progressed, the screen in front of the recording apparatus being removed. Furthermore, self-competition (also serving as incentive) was employed by having the subjects attempt to exceed a point marked out on the drum. This limit was obtained from the exhaustion points gained from the non-incentive series (Column II).

Experiments were made on the right arm and the right leg of four subjects. Each subject appeared at the laboratory twice a day at times so arranged that only one subject was present during the work periods. The arm series was held in

[1] Quoting Arps, *op. cit.*, "Exhaustion as here used means nothing more than the ergograph load could not be budged for two successive attempts; it certainly does not imply an anesthetic condition of any part of the neuro-muscular chain." As the term is used in this experiment, similar bodily conditions are implied. Exhaustion is merely a disability on the part of the subject to lift the weight at hand. A reduction in weight has been shown to cause a revived performance, as well as incentive effects, etc.

the morning from approximately ten to eleven-thirty. The leg experiment, from four to six in the afternoon. The approximate time for each experimental performance for the arm was about ten minutes. This included the first work period, the rest interval, and the control work period which followed. For the leg experiment, the time ranged from ten to twenty-five minutes. The whole experiment extended from the early part of December, 1925, to the first of April, 1926.

Summary:

From the data as presented in Chapter III, certain conclusions may be drawn:

1. The effect of practise is more noticeable in progressive performances of an unfatigued muscle group than in a group previously fatigued. The second work periods, with the fatigue effects present, show less change through practise than do the first work periods.

2. The effects of the variations in procedure were seen both in experiments on the right leg and the right arm, for all four of the subjects.

3. Recovery, as shown by the amount of work done in the second work period, seemed greater in proportion (under these experimental conditions) for the arm than for the leg, the same time being allowed for recuperation.

4. Moderate variations in performance for any one work condition were found in the records of each of the four subjects. This variability seemed to decrease as the weights increased. Similar decrease was noted when the subject exerted greatest effort, in the competition series, although a uniform tendency in this direction for every combination was not apparent.

5. Variation among the subjects was large enough in both the arm and the leg experiments to make the results as they appeared fairly indicative of different degrees of physical capacity.

6. Effects of work were still present after a rest of two and four minutes respectively.

7. Recovery from work was greater after a four-minute rest period than after a two-minute rest interval.

8. Less work was produced in the first period when heavy weights were employed than when light weights were used.

9. More work was accomplished in the second work periods, in general, which followed a first period of heavy-weight performance. Inversely, the second work period following the performance with the light weights showed less work accomplished than when following heavy weights.

10. Where approximately equal quantitative amounts of work are performed with the respective weights in the first work period, the amount of work done in the second work period seems greater when following a light weight than when following a heavy weight.

11. More work was accomplished when the subject competed with a former record, and with the results visible, than when the same task was performed without competition and with results screened. This is also true even if both work periods are added together and considered as a whole.

12. The extra exertion by the subject in the competition series showed itself in diminished output in the second work period, even when this later period followed a four-minute rest. The extra work produced by incentive called for greater time for recovery.

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